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30mm Plumbicon* camera tubes with fibre-optic faceplate, anti-comet-tail gun, and lightpipe

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UDC 621.385.832.56: 621.397.61

A description is given of two new types of 30mm (1¼in) diameter Plumbicon camera tube which feature:

1) *A fibre-optic input window, extending the usability of the Plumbicon tube to low light levels, medical X-ray television systems, infrared observations, and other fields, without the necessity of incorporating bulky lens systems.*
2) *An anti-comet-tail gun which enables the user to cope with scenes containing extreme high-lights and high contrasts.*
3) *A lightpipe which reduces lag at low signal levels by applying a low background illumination.*

The construction of the tube and the operation of the anti-comet-tail gun and the lightpipe are described. Sensitivity, speed of response, resolution and transfer characteristic are all discussed and data given.

INTRODUCTION

A television camera tube converts optical image information into electrical signals. Light entering the camera pick-up tube is transformed into electrostatic charges by a photosensitive layer to form a charge density pattern which corresponds to the optical image. The charge pattern is then retained by a storage element until read out by an electron scanning beam.

Early camera tubes used a photocathode, that is, a cathode from which the electrons are released by photoemission caused by an incident light beam. Examples of tubes which employed this principle are the Iconoscope and image Iconoscope. The image orthicon, which was developed during World War II as a device for low light level television, also belongs to this group of tubes. The need for improvement in picture quality gradually increased the complexity of these devices, a fact which is clearly demonstrated by the image isocon. This tube was a further development of the image orthicon, and, although its principles were outlined as long ago as 1948, they were too complex to put into practice until quite recently.

In contrast to the previous class of camera devices which use photocathodes, camera tubes which are based on the principle of photoconductivity are relatively simple. In these tubes the photosensitive layer acts as both the light transformer and the charge density pattern store. Experience has shown that, because of their constructional simplicity, these devices are preferable in many applications. The most important representatives of this second class are the antimony trisulphide vidicon and the Plumbicon camera tubes. The Plumbicon tube is now widely accepted as the most suitable camera tube for broadcast television and, in particular, colour broadcast television. This tube is also widely used in industrial closed-circuit and medical X-ray television systems.

Plumbicon camera tube penetration into the low light level television sector, however, has been relatively slow because each new application has individual requirements to fulfil. Such applications usually require the Plumbicon tube to be used in conjunction with an image intensifier (this is also the case in medical X-ray television) and this often means that the image intensifier is also specific to the particular task. The main differences in application requirements concern resolution, sensitivity, and the size of the useful image field in the electronoptical system.

It is customary in such an electronoptical system to use conventional optical coupling techniques. However, the fast lenses required are bulky and heavy, and in operation, are not always optimally focused. Other disadvantages include loss of light, vignetting, and reduced corner resolution. An alternative approach to the assembly of electronoptical systems has been made possible by recent developments in fibre-optic plates. Using one of these fibre-optic plates as the camera tube input window avoids all the disadvantages of a lens coupling.

Two other factors which reduce picture quality are blooming and comet-tailing. Blooming is a loss of picture in areas adjacent to a stationary highlight, whilst comet-tailing is the term applied to the trails of light which follow a moving highlight on the television screen. These effects are overcome successfully by the use of an anti-comet-tail (ACT) gun in the camera tube.

Both of these new developments, the fibre-optic faceplate and the ACT gun, are incorporated in two new 30mm (1¼in) diameter Plumbicon tubes, the 25XQ and 26XQ. In addition, both tubes feature a lightpipe which permits the external adjustment of internal bias illumination.

This article deals with the specific properties of these tubes and is intended to contribute toward a better understanding of the features and limitations of the Plumbicon tube when used as an element in advanced electronoptical systems.

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*Registered trade mark for television camera tubes

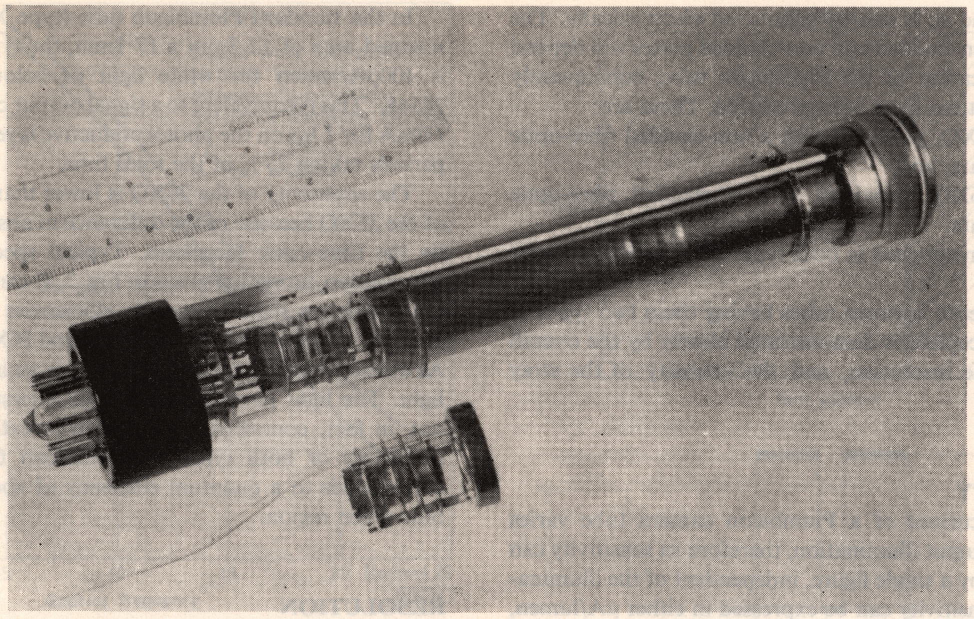


Fig. 1—30mm diameter Plumbicon tube

CONSTRUCTION

The new Plumbicon tubes described here employ magnetic focusing and deflection. Externally they resemble the standard Plumbicon tube, type XQ1020 (Fig. 1).

A fibre-optic faceplate is sealed to one end of the soft glass cylinder which forms the tube envelope. In the finished state the outer face of the fibre-optic faceplate shows a flatness of better than 1µm. The coefficient of expansion of the soft glass cylinder is matched with that of the special glasses used for the fibre optics. The other end of the soft glass cylinder is matched (by a suitable glass transition) to the hard glass part required for the tube base. At the faceplate end, the tube incorporates a metal signal electrode contact in the form of a ring round the outside of the glass tube. Connection is made between this external signal electrode and the internal signal plate by means of a metal feed-through connector. The signal plate is formed by a transparent conductive coating on the inside of the fibre-optic faceplate. The photoconductive layer of lead monoxide (PbO) is deposited on this coating.

The gun assembly is a long seamless metal cylinder with the ACT gun at one end and at the other end (but insulated from it) the mesh. The cylinder is clamped rigidly at both ends within the glass envelope of the tube to provide perfect mechanical concentricity. All insulating junctions are of brazed metal-ceramic, which also make for rigidity of construction.

In the ACT gun section provision is made for supporting the lightpipe in position. The lightpipe is fused internally to the envelope at the pumpstem as the tube is being sealed. This construction gives good uniformity of the illumination of the scan side of the lead monoxide layer.

FIBRE OPTICS

The general performance of a camera tube which has a fibre-optic faceplate depends on the quality and properties of the fibre-optic plate used. Because different manufacturers use different materials and production techniques, the quality and properties of fibre-optic plates vary considerably. Two variables are mentioned here, of which the second is of particular importance to the general performance of a camera tube:

1) Fibre-optic faceplates may be made from square or hexagonal bundles of fibres;
2) Fibre-optic faceplates may have either cladded fibres, providing extra-mural absorption, or non-cladded fibres.

In the non-cladded fibre-optic faceplates, light which falls on the surface areas between neighbouring fibres is also transmitted but not guided. This effect, and incidental light-coupling between fibres, gives rise to a large amount of stray light. Cladded fibres were introduced to avoid this effect and to improve resolution.

However, under certain conditions cladded plates can show up a weak "chicken-wire" pattern. (In plates made from square bundles a similar effect may be seen as a regular array of black spots occurring at the corners of the squares.) Generally the contrast of this pattern increases as the angle of incidence of the light increases. Since the plates are used in diffuse illumination, this pattern may be visible in the televised image. In some applications the chicken-wire effect of cladded plates may impede the interpretation of low contrast images (for example, in medical X-ray television and electron microscopy). However, in low contrast images the stray light which occurs in non-cladded plates is uniform and so it can be subtracted electronically. The choice between cladded and non-cladded plates will depend on the application of the Plumbicon tube, consequently two kinds of tube have been produced. These are:

1) the 25XQ, provided with a non-cladded fibre-optic faceplate, and,
2) the 26XQ, provided with a cladded fibre-optic faceplate.

The fibre diameter used in both types of faceplate is about 7μm.

The difference between tubes having these two types of fibre-optic faceplate is demonstrated clearly by the overall sensitivity, the resolution, and the intensity of the stray light effect.

SENSITIVITY

The output current of a Plumbicon camera tube varies linearly with input illumination, therefore its sensitivity can be indicated by a single figure, independent of the illumination level. Sensitivity can be expressed in either μA/lumen, or as the signal output for a given illumination level at the tube face. In the latter case, the value depends upon the size of the scanned area on the photoconductive layer and also on the fraction of the total time which is not used for active scanning (due to blanking periods).

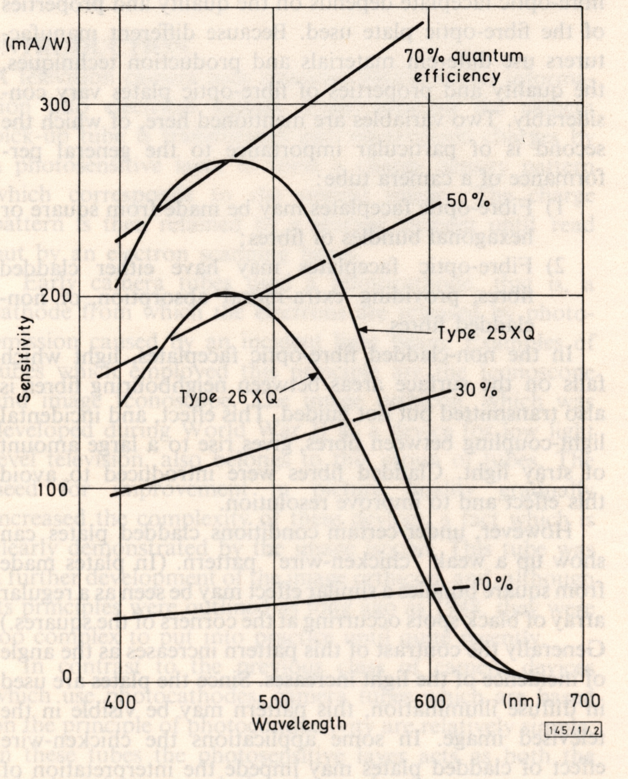


Fig. 2—Typical spectral response characteristics of 25XQ and 26XQ

In the standard Plumbicon tube (type XQ1020) with a scanned area of 12·8mm x 17·1mm, the typical sensitivity is 400μA/lumen for white light of colour temperature 2854K. This is equivalent to a signal output current of about 110nA for 1 lux on the photoconductive layer with blanking periods taking 25% of the total time.

The sensitivity of the 26XQ is lower than the sensitivity of the 25XQ because of the difference in absorption of light by the fibre-optic faceplates. Typical spectral sensitivity distribution curves are given in Fig. 2. It can be seen that in the blue-green region quantum efficiencies of about 70% and 50% are obtained for the 25XQ and 26XQ respectively. As already mentioned, the difference is mainly due to stray light. The light passing through the interstitial glass does not, in fact, contribute to image information. The useful sensitivity of both types of Plumbicon tube, therefore, corresponds to a quantum efficiency of about 50% in the blue-green region.

RESOLUTION

The photoconductive layer used in the 25XQ and the 26XQ is a slightly modified version of the standard lead monoxide layer used in type XQ1020. This modification helps to compensate for the loss in resolving power caused by the fibre-optic faceplates. Typical modulation transfer characteristics for the 25XQ and the 26XQ are given in Figs. 3 and 4 respectively. The curves for green light and blue light are slightly different, the resolution of the Plumbicon tube increasing toward the shorter wavelengths.

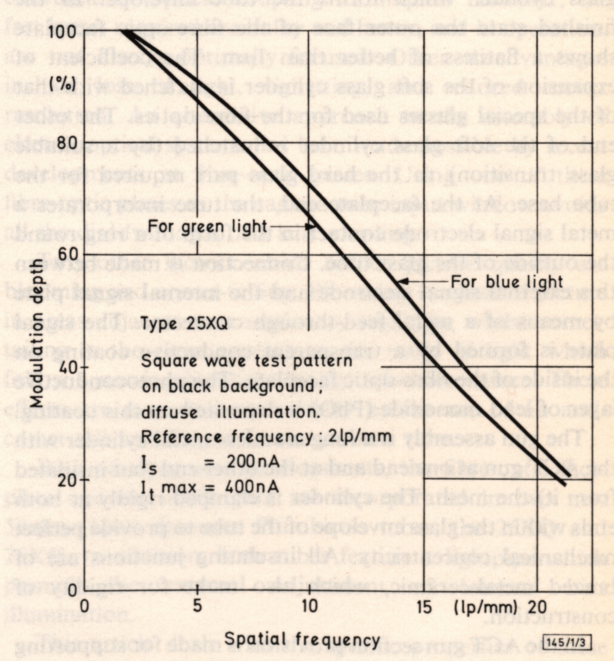


Fig. 3—Typical modulation transfer characteristics of 25XQ

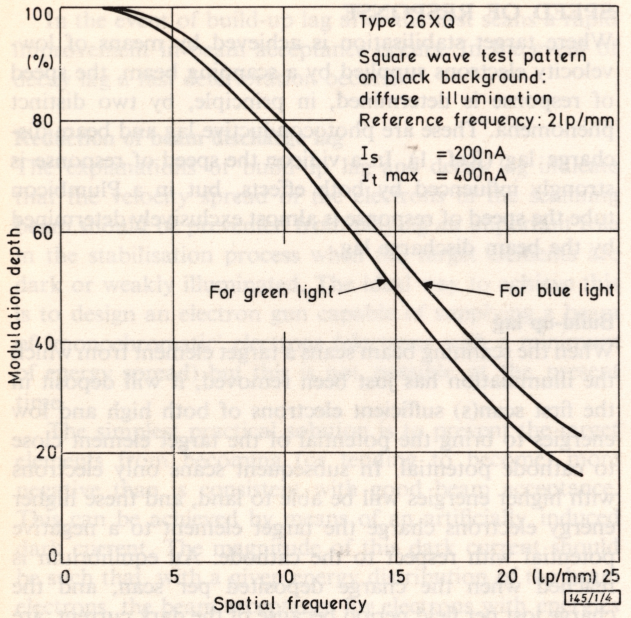


Fig. 4—Typical modulation transfer characteristics of 26XQ

For the type 26XQ (with cladded fibres) the modulation depth at 15 line-pairs per millimetre is about 56% in blue light and 50% in green light. For type 25XQ (non-cladded fibres) typical figures at the same spatial frequency are about 48% and 42% for blue and green light respectively. With a scanning raster of 12·8mm x 17·1mm, the spatial frequency of 15 lp/mm (line-pairs per millimetre) on the target corresponds to 384 television lines per picture height, or to a video frequency of about 4·8MHz under standard scanning conditions (625 television lines).

Method of measurement

A small square-wave test pattern comprising bars at 2 lp/mm and 15 lp/mm on a black background was applied directly to the Plumbicon tube faceplate. The response to 2 lp/mm pattern was taken as 100%. Diffuse illumination was used when these measurements were taken as this approximates to light originating from a phosphor screen deposited on a fibre-optic output window.

Different results are obtained if a test pattern having a white background is used, especially with a lower reference frequency. The difference in results is caused mainly by stray light. Relative measurements of stray light have been made by employing the method illustrated in Fig. 5. A test chart is divided into three equal vertical bars; the middle bar is white, the two outer bars are black. In the centre of the white area is a small black square (sizes are indicated in the figure).

An oscillogram of the video signal from a scanning line which passes through the centre of this black square is shown in the lower part of Fig. 5. If stray light is present then the square will become grey and the signal from the black areas will have the form shown. The ratio h_1/h_2 can now be taken as a measure of the amount of stray light present. Table 1 lists typical values of this ratio for the standard Plumbicon tube as well as the 25XQ and 26XQ. The values in parentheses are obtained when the anti-halation glass disc is omitted from the standard Plumbicon tube face. When this is done, halation effects in the entrance window greatly increase the amount of stray light present. It can also be seen from Table 1 that a large quantity of stray light is present in the 25XQ (non-cladded fibres), especially for green light.

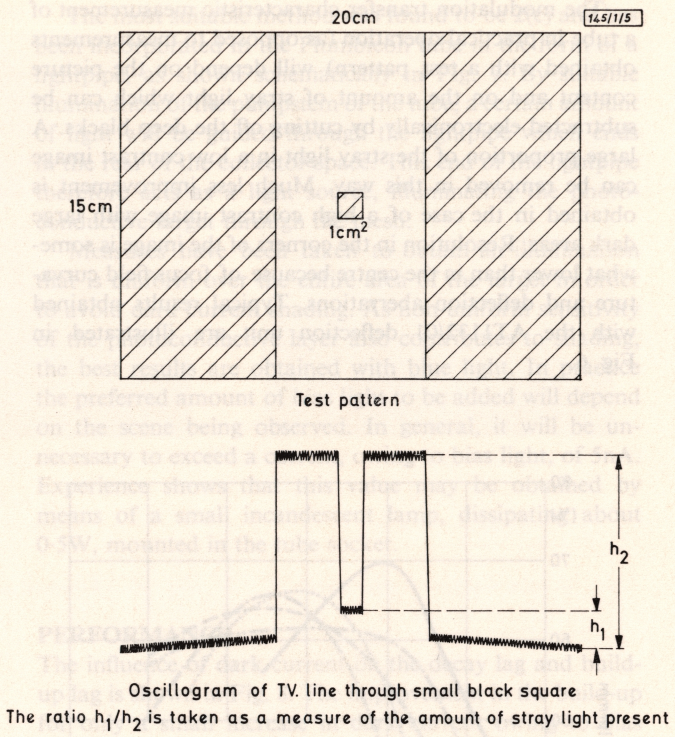

20cm
145/1/5
15cm
$1cm^2$
Test pattern
h_2
h_1
Oscillogram of TV. line through small black square
The ratio h_1/h_2 is taken as a measure of the amount of stray light present

Fig. 5—Method for measuring stray light

TABLE 1

Amount of stray light in types XQ1020, 25XQ and 26XQ

Type	Colour of light	h_1/h_2 (%)
XQ1020	red	5(16)
	green	4(12)
	blue	4(14)
25XQ	green	26
	blue	17
26XQ	green	8
	blue	6

The modulation transfer characteristic measurement of a tube in practical operation (as opposed to measurements obtained with a test pattern) will depend on the picture content and on the amount of stray light which can be subtracted electronically by cutting off the deep blacks. A large proportion of the stray light in a low contrast image can be removed in this way. Much less improvement is obtained in the case of a high contrast image with large dark areas. Resolution in the corners of the image is somewhat lower than in the centre because of focus field curvature and deflection aberrations. Typical results obtained with the AT1132/01 deflection unit are illustrated in Fig. 6.

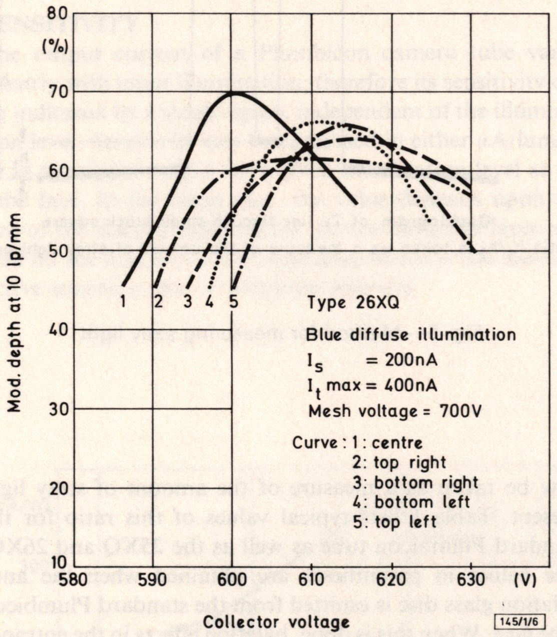


Fig. 6—Central and corner resolution

The central modulation depth, at a collector voltage of 600V and at 10 lp/mm, is about 70% for optimum focusing at the centre of the scanning area. In the corners, however, the modulation depth varies between 45% and 60%. It is possible to reach a compromise between central and corner resolution by choosing a slightly higher collector voltage (for example 610V) and retaining the same magnetic focus field strength. If this is done, the modulation depth is better than 60% over the whole scanning area. Central resolution is, however, somewhat lower than optimum.

Corner resolution can be raised without loss of central resolution to values which exceed 60% by modulating the collector voltage. In Fig. 6 a good choice of collector voltage would appear to be 600V with an additional modulation voltage of about 15V in the corners; but the optimum amplitude of focus modulation voltage and the uniformity of corner resolution depend strongly on the particular type of deflection unit used.

SPEED OF RESPONSE

Where target stabilisation is achieved by means of low-velocity electrons supplied by a scanning beam, the speed of response is determined, in principle, by two distinct phenomena. These are photoconductive lag and beam discharge lag (Ref. 1). In a vidicon the speed of response is strongly influenced by both effects, but in a Plumbicon tube the speed of response is almost exclusively determined by the beam discharge lag.

Build-up lag

When the scanning beam scans a target element from which the illumination has just been removed, it will deposit in the first scan(s) sufficient electrons of both high and low energies to bring the potential of the target element close to cathode potential. In subsequent scans only electrons with higher energies will be able to land, and these higher energy electrons charge the target element to a negative potential with respect to the cathode. An equilibrium is reached when the charge deposited per scan, and the charge lost per field period because of the dark current, are equal. At equilibrium the potential of the element may be one volt or more negative with respect to the cathode. The greater the beam current and the smaller the dark current, the more negative the element will become. The beam acceptance will be low (or the beam resistance will be high).

When the target element under consideration is subsequently exposed to a weak illumination, the change in its potential in a field period owing to photoconduction will be small (a signal current of 20nA corresponds to only about 0·6V potential change). On the first scans only the electrons with relatively high energies can participate in the stabilisation process. In subsequent scans, when the potential of the element is gradually increasing, more and more lower energy electrons will participate in the process (increasing beam acceptance or decreasing beam resistance). Ultimately a new equilibrium is reached in which the beam just replenishes per scan the charge lost per field period from the sum of the dark current and the photoconductive current. This slow increase of the beam acceptance, and hence of the signal-current, after a change in illumination from black to white, is termed build-up lag and is measured as the percentage of the ultimate signal current reached at a specified time after illumination has been applied.

Decay lag

It can be deduced from the previous section that when a target element is weakly illuminated its potential between scans will not differ much from the potential corresponding to dark. When the illumination is removed the beam acceptance will be low and will, as the potential of the element decreases further, become lower with each scan. Finally an equilibrium is reached, determined by a balance between the charge deposited per scan and the charge lost per field period because of the dark current. This gradual decrease of the beam acceptance and hence of the signal-current after a change in illumination from white to black is termed decay lag and is measured as the percentage of the original white signal-current left at a specified time after the illumination has been removed.

In the event of build-up lag after the first scans a rapid improvement in beam acceptance occurs. In the event of decay lag a fast deterioration occurs.

Reduction of beam discharge lag

The explanations of build-up lag and decay lag indicate that the velocity spread of the electrons in the scanning beam should be prevented from playing an important role in the stabilisation process when the target elements are dark or weakly illuminated. The ideal way to achieve this is to design an electron gun capable of supplying a beam of 'monochromatic' electrons (electrons with a minimum of energy spread) but this is not possible at the present time.

The simplest practical solution is to prevent the target elements from becoming (or tending to become) more negative than is consistent with good beam acceptance. This can be achieved by means of an artificially induced dark current. The magnitude of this dark current should be such that, with a given energy distribution of the beam electrons, the beam acceptance for electrons with energies of zero to only a few eV will be sufficient to replenish per beam scan the charge lost per field period.

This artificial dark current can be achieved as follows:

1) Add a "dope" to the target material to induce some conductivity, although this approach may adversely affect the other important characteristics of the lead oxide layer (for example, temperature independence of the dark current).
2) Apply bias lighting:
   a) Project some light on to the faceplate of the Plumbicon tube (directly via the optics, or via the colour splitter). This method, though possible in a camera, is impracticable with fibre-optic tubes.
   b) Conduct some light from the Plumbicon tube heater to the target (this explains why the XQ1020 with the 2W heater shows less beam discharge lag than the 55875; some heater light is conducted through the envelope to the target).
   c) Illuminate the target at scan side.

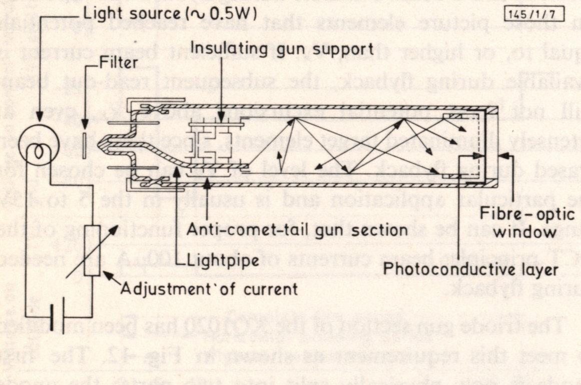


Fig. 7—Schematic diagram of Plumbicon tube fitted with a lightpipe

The most suitable method was found to be 2(c) and has been incorporated in the Plumbicon tube in the form of a lightpipe, as shown schematically in Fig. 7. By suitable illumination of the pumpstem of the tube, a certain amount of light will be guided through the lightpipe which ends in the rear of the collector space. This end of the lightpipe therefore acts as a light source, illuminating the photoconductive target through the mesh.

Measures have been taken to obtain an illumination that is uniform over the entire area of the target in order to avoid dark current shading. As non-uniform sensitivity of the photoconductive layer also contributes to shading, the best results are obtained with blue light. In practice the preferred amount of bias light to be added will depend on the scene being observed. In general, it will be unnecessary to exceed a current, owing to bias light, of 5nA. Experience shows that this value may be obtained by means of a small incandescent lamp, dissipating about 0·5W, mounted in the tube socket.

PERFORMANCE

The influence of dark current on the decay lag and build-up lag is shown in Fig. 8. The improvement in the build-up for only a small increase in dark current owing to bias light is particularly remarkable.

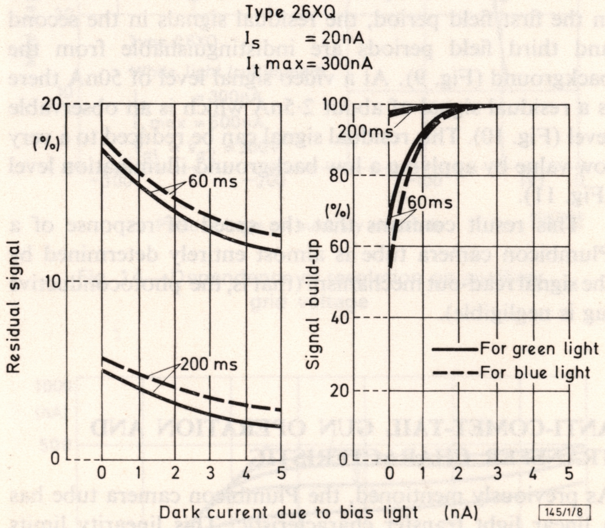
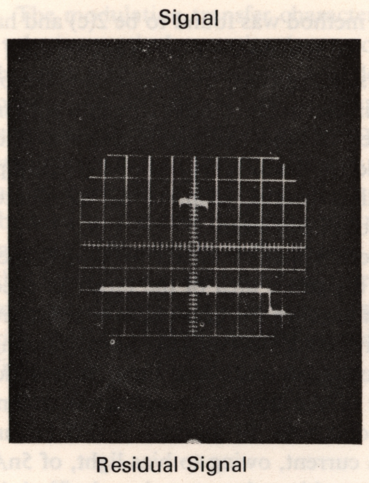


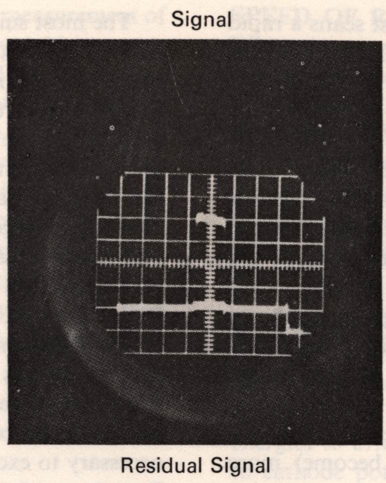
Fig. 8—Reduction of decay lag and build-up lag at a low signal current with bias illumination

Figs. 9, 10, and 11 show that the speed of response is determined by the beam discharge lag. The oscillograms were obtained when using a 25mm (1in) diameter Plumbicon tube with interlaced scanning, in which the entire area is read-out in each field. In the figures, the video signal is represented at field frequency.



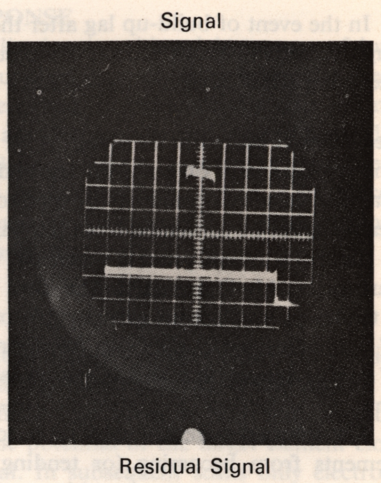
$I_s = 200nA$
$I_t max = 400nA$

Fig. 9—No residual signal visible



$I_s = 50nA$
$I_t max = 400nA$

Fig. 10—Residual signal clearly visible



$I_s = 50nA$
$I_t max = 400nA$
bias light added

Fig. 11—Residual signal eliminated by an additional 5nA of dark current

The object is a white bar on a black background which is illuminated once every three field periods for a very short time. During the first scan after illumination almost all of the information is read-out, leaving very little residual signal. For a peak-white video signal level of 200nA in the first field period, the residual signals in the second and third field periods are indistinguishable from the background (Fig. 9). At a video signal level of 50nA there is a residual signal of about 2·5nA which is an observable level (Fig. 10). This residual signal can be reduced to a very low value by applying a low background illumination level (Fig. 11).

This result confirms that the speed of response of a Plumbicon camera tube is almost entirely determined by the signal read-out mechanism (that is, the photoconductive lag is negligible).

ANTI-COMET-TAIL GUN OPERATION AND TRANSFER CHARACTERISTIC

As previously mentioned, the Plumbicon camera tube has a linear light transfer characteristic. This linearity limits the upper end of the dynamic range of the Plumbicon tube to a level determined by the amount of beam current which can be accepted without introducing loss of resolution or unacceptable lag.

It has become customary in broadcast television to limit the beam current to a level which is sufficient to stabilise twice the normal peak white signal output current to be expected from the scene being televised. When highlights occur in excess of this level, the Plumbicon tube target will be unstabilised locally, and the picture elements being viewed will lose more charge between successive scans than the beam can replenish. In the picture, not only is there a loss of detail in these highlight areas, but blooming due to beam pulling, and comet-tails following moving highlights, are also observed. It is possible to reduce these effects by limiting the maximum potential excursion on the target. This is done by choosing a lower signal plate voltage (about 20V, as opposed to 45V). This results, however, in a lower field strength across the target, which causes a slight reduction in the sensitivity, and there is an occasional slight tendency to picture burn-in.

Blooming and comet-tailing can be suppressed with the aid of a new gun design. This is the anti-comet-tail gun (Ref. 2) and it is incorporated in the 25XQ and 26XQ.

The ACT gun design is based on the idea of limiting the potential excursions of the target picture elements. An effective limiting can be obtained if each line read-out is preceded by a short high-intensity beam scan applied during the line flyback. This scan replenishes all charge in excess of that which can be replenished fully by the normal scanning beam during read-out. The light transfer characteristic will now show a saturation level and a "knee".

With the ACT gun in operation, the cathode is pulsed at a positive potential (V_k) during the line flyback. As a result of this a beam available during flyback can land only on those picture elements that have reached potentials equal to, or higher than, V_k. If sufficient beam current is available during flyback, the subsequent read-out beam will not meet potential excursions above V_k, even at intensely illuminated target elements, since these have been erased during flyback. The level of V_k can be chosen for the particular application and is usually in the 5 to 15V range. It can be shown that, for proper functioning of the ACT principle, beam currents of about 100μA are needed during flyback.

The triode gun section of the XQ1020 has been modified to meet this requirement as shown in Fig. 12. The first anode is now physically split into two parts; the anode a_1, and the limiter a_2, which remain electrically interconnected. The limiter-to-cathode distance and the size of the limiting aperture have been increased. An auxiliary grid, g_2, is placed between the anode and the limiter.

During read-out the auxiliary grid is maintained at a potential near to that of a_1 and a_2. The crossover will then be positioned as shown in the upper part of Fig. 12. During line flyback a large negative pulse is applied to g_2. The lens action of the a_1, g_2, a_2 electrode configuration now converges the beam on the aperture in the limiter which greatly increases the proportion of the beam passing through this aperture (lower part of Fig. 12). In the gun configuration chosen the voltage on the auxiliary grid during flyback is between 5V and 10V.

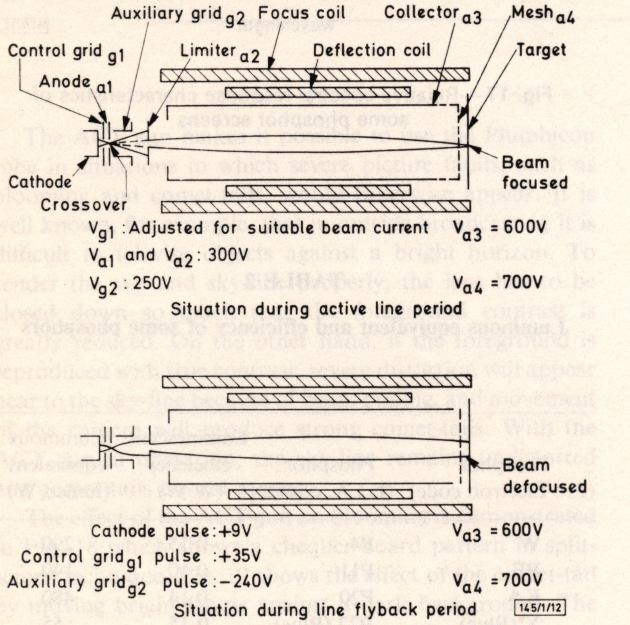


Fig. 12—Fibre-optic Plumbicon tube with ACT gun

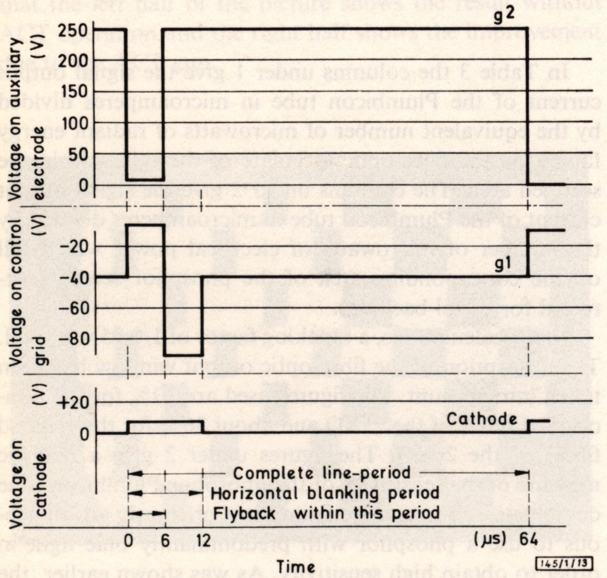


Fig. 13—Typical pulses during ACT operation

A typical example is given in Fig. 13 of the pulses on the gun electrodes during ACT operation. A positive pulse is applied to the control grid during flyback to increase the current available. The amplitude of this pulse may be 30 to 35V with respect to the voltage during read-out. The control grid voltage is brought below cut-off during the second half of the blanking period to allow time for black level clamping to take place.

The amplitude of the pulse on g_2 is nearly 250V as, during read-out, the auxiliary grid potential should not be appreciably different from the voltage on the anode and limiter. Fig. 14 shows that this would otherwise cause a significant loss in the resolution (the voltage on a_1 and a_2 was 300V during the measurement).

Fig. 15 shows typical signal output characteristics in ACT operation. The lower part of the output curve remains a straight line, and in this region the ACT pulses have no

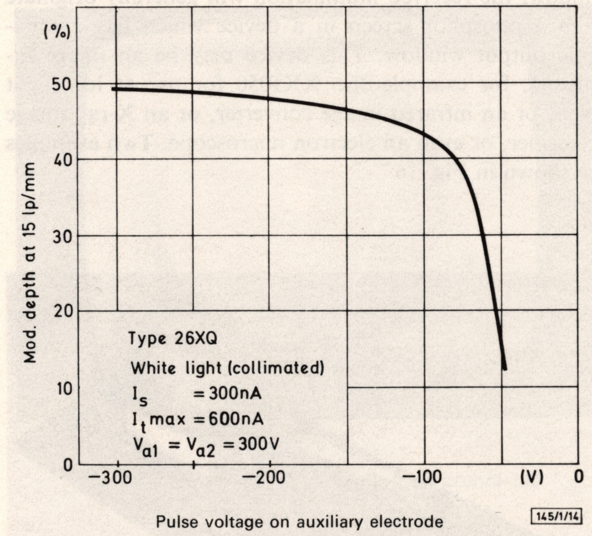


Fig. 14—Dependence of resolution on auxiliary grid voltage

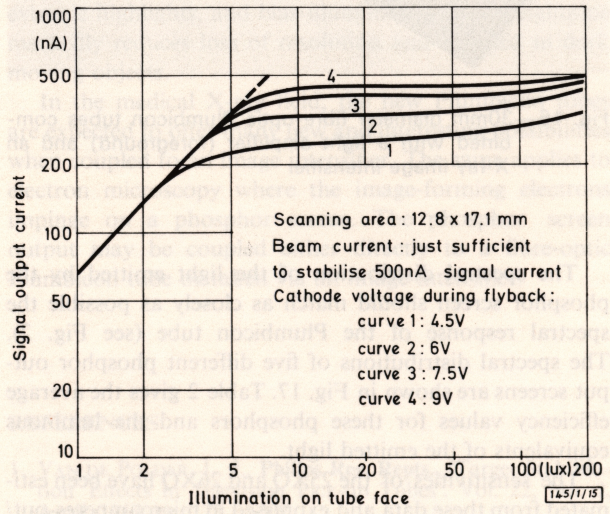


Fig. 15—Typical signal output characteristics of 25XQ and 26XQ in ACT operation

influence whatever: gradation, resolution, and lag remain unchanged. The output current still increases after the knee has been reached, but now the rate of increase is much slower. Rounding off of the knee is caused by the large spread in velocities of electrons in the high-intensity flyback beam. A grey scale is therefore found even in the highlights, although it is greatly compressed.

Experiments with tubes exposed to scenes which contain highly reflective objects and bright incandescent lamps, have demonstrated clearly that highlights up to about 5 lens stops in excess of normal picture white are handled without comet-tails, blooming or other unnatural effects in the picture.

APPLICATIONS

As these tubes are provided with a fibre-optic entrance window, the received illumination will generally originate from a phosphor screen in a device which has a fibre-optic output window. This device may be an image intensifier, for example the XX1050 for use at low light levels, or an infrared image converter, or an X-ray image intensifier, or even an electron microscope. Two examples are shown in Fig. 16.

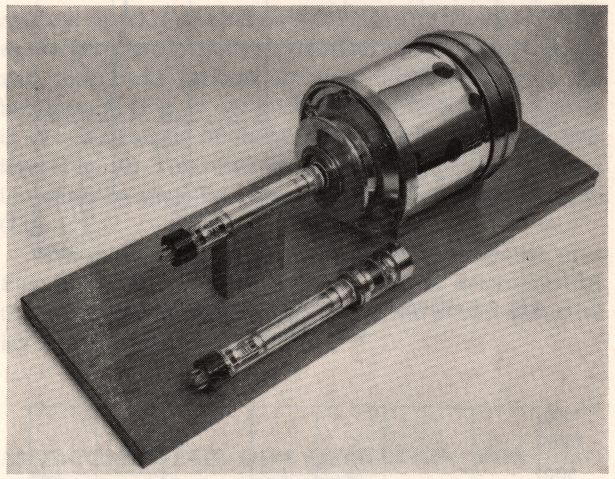


Fig. 16—30mm diameter fibre-optic Plumbicon tubes combined with a light amplifier (foreground) and an X-ray image intensifier

The spectral distribution of the light emitted by the phosphor screen should match as closely as possible the spectral response of the Plumbicon tube (see Fig. 2). The spectral distributions of five different phosphor output screens are shown in Fig. 17. Table 2 gives the average efficiency values for these phosphors and the luminous equivalents of the emitted light.

The sensitivities of the 25XQ and 26XQ have been estimated from these data and expressed in microamperes-out/microwatts-in for each of the five types of output phosphor. The figures which resulted are given in Table 3.

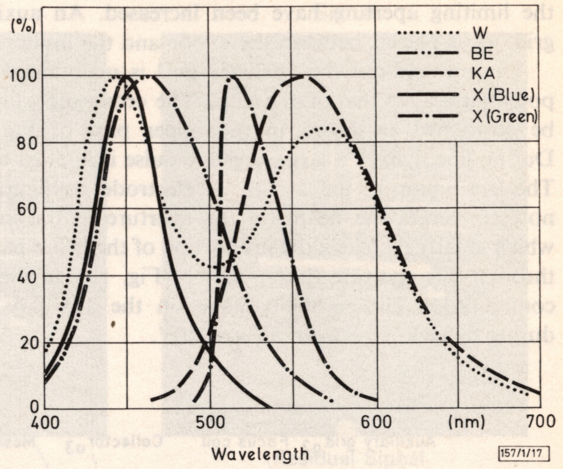


Fig. 17—Relative spectral response characteristics of some phosphor screens

TABLE 2

Luminous equivalent and efficiency of some phosphors

Phosphor (Pro Electron code)	Phosphor (E.I.A. code)	Luminescent efficiency (W/W)	Luminous equivalent (lumen/W)
W	P4	0·15	290
BE	P11	0·10	140
KA	P20	0·14	480
X (Blue)	P22 (Blue)	0·15	55
X (Green)	P22 (Green)	0·06	530

In Table 3 the columns under 1 give the signal output current of the Plumbicon tube in microamperes divided by the equivalent number of microwatts of radiant energy falling on the fibre-optic faceplate of the tube within the scanned area. The columns under 2 give the signal output current of the Plumbicon tube in microamperes divided by the number of microwatts of electrical power which fall on the corresponding area of the phosphor screen (corrected for metal-backing).

In the calculations, a blanking factor of 1/0·75 was used. The absorption of the fibre-optic output window has been taken into account. The figures used are 10% for the non-cladded fibres of the 25XQ and about 30% for the cladded fibres of the 26XQ. The figures under 2 give a realistic measure of the sensitivity of the phosphor-Plumbicon tube combination. From these figures it is obviously advantageous to use a phosphor with predominantly blue light in order to obtain high sensitivity. As was shown earlier, the resolution is also better when blue light is used.

TABLE 3

Sensitivity of Plumbicon tubes 25XQ and 26XQ for different phosphor output screens

Phosphor (Pro Electron code)	Phosphor (E.I.A. code)	Sensitivity in μA/μW 1 per μW on tube face 25XQ	 26XQ	2 per μW on phosphor screen 25XQ	 26XQ
W	P4	0·21	0·16	0·027	0·017
BE	P11	0·30	0·23	0·027	0·017
KA	P20	0·17	0·13	0·021	0·013
X (Blue)	P22 (Blue)	0·29	0·23	0·038	0·024
X (Green)	P22 (Green)	0·27	0·21	0·014	0·009

The ACT gun makes it possible to use the Plumbicon tube in situations in which severe picture faults, such as blooming and comet-tails, would otherwise appear. It is well known, for example, that in outside broadcasting it is difficult to televise objects against a bright horizon. To render the sky and sky-line properly, the lens has to be closed down so much that the foreground contrast is greatly reduced. On the other hand, if the foreground is reproduced with true contrast, severe distortion will appear near to the sky-line because of beam pulling, and movement of the camera will produce strong comet-tails. With the ACT gun in operation, the sky-line remains undistorted and comet-tails do not appear.

The effect of the ACT gun on blooming is demonstrated in Fig. 18 which shows a chequer-board pattern in split-screen technique. Fig. 19 shows the effect of the comet-tail by moving bright lamps against a dark background. The brightness of the lamps corresponds to about 250 lux on the target. The split-screen effect is obtained when the ACT pulses are applied to the gun electrodes during only the second half of each line scanning period. This means that the left half of the picture shows the result without ACT operation and the right half shows the improvement due to the ACT gun.

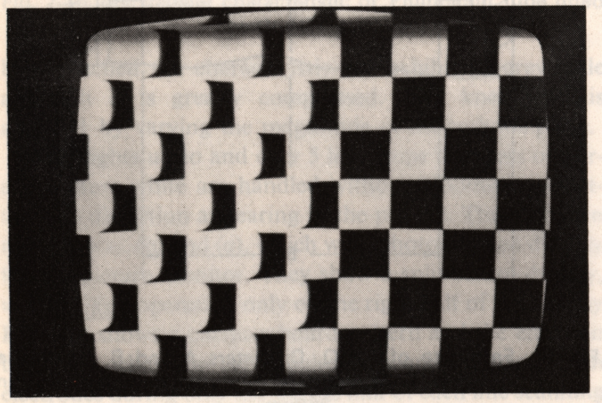


Fig. 18—Effect of ACT operation on blooming

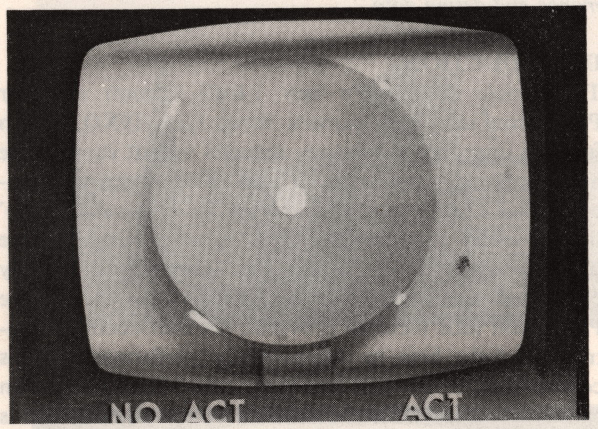


Fig. 19—Effect of ACT operation on comet-tail

High contrasts are often found in low light level television. The ACT gun enables the camera user to cope with extreme highlights, and bias illumination via the lightpipe markedly reduces loss of resolution and contrast in dark moving objects.

In the medical X-ray field, the new Plumbicon tubes are expected to offer many new and interesting possibilities when coupled to an image intensifier. The same applies to electron microscopy where the image-forming electrons impinge on a phosphor screen. The phosphor screen output may be coupled either directly to a fibre-optic Plumbicon tube or taken via an image intensifier.

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One-inch diameter Plumbicon* camera tube type 19XQ

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UDC 621.832.56—181.4:621.397.61

The new 1-inch (25mm) diameter Plumbicon television camera tube, type 19XQ, is described. Design features on improved resolution, reduced output capacitance, improved registration, controlled light bias to improve lag performance and the anti-comet-tail gun are given with details of performance and design data.

INTRODUCTION

This article describes a new 1-inch (25mm) diameter Plumbicon television camera tube, type 19XQ, which features improved resolution, reduced output capacitance and improved registration. It also incorporates the anti-comet-tail (ACT) gun which gives an adjustable 'knee' light transfer characteristic; this is of particular value when televising scenes where the lighting is not easily controlled, for example outside broadcasts. Lastly, the Plumbicon tube includes provision for introducing a controllable light bias to improve lag performance. This combination of features makes the new 1-inch Plumbicon camera tube the ideal choice to meet the high standards required in the design of compact 3 or 4 tube broadcast colour cameras.

CHOICE OF OPTIMUM IMAGE FORMAT FOR BROADCAST CAMERAS

Most of the characteristics of a broadcast camera can be considered in two groups. The first group includes such things as resolution, signal-to-noise ratio and long term operational stability, where well defined requirements have to be met but there is no advantage in exceeding these requirements. The second group includes such things as sensitivity, camera size, and weight, which are capable of continual improvement.

Reducing the image format, that is choosing a smaller tube size, tends to improve the performance in respect of items in group two, while it degrades it in respect of items in group one. In consequence the optimum format will get smaller as improvements are made in tube technology. The last such reduction occurred with the replacement of the 4½-inch image orthicon tube (image format 24 × 32mm) by the 30mm Plumbicon tube (image format 12·8 × 17·1mm). Now, with the introduction of the 19XQ, the optimum format is 9 × 12mm.

19XQ FEATURES

The 19XQ Plumbicon camera tube is manufactured in two versions, that is, rear loading and front loading. The front loading version is mechanically interchangeable with the XQ1070 series, while in the rear loading version the contact ring is replaced by a ceramic ring having a special low capacitance contact.

Resolution

Continued development of the lead oxide photoconductive layer has made it possible to obtain approximately the same resolving power in the 19XQ as was obtained in the 30mm tube. This has been achieved without the loss of any of the other important Plumbicon tube features.

Centring

To facilitate good registration when tubes are used in colour cameras, an improved construction has been introduced into the rear loading version. This results in close concentricity of the collector electrode and mesh with the faceplate of the tube. A ceramic reference ring is attached to the faceplate so that it is concentric within close limits with the inner diameter of the mesh ring. Fig. 1 gives preliminary information on the dimensions at the faceplate end of the tube.

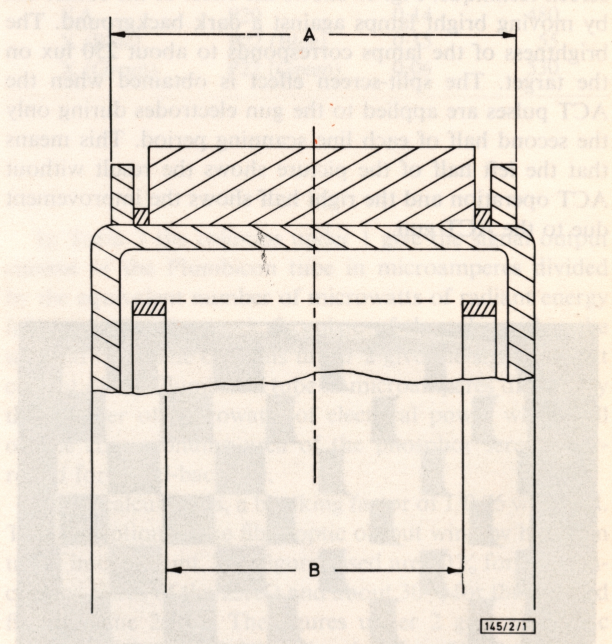


Fig. 1—Faceplate of 19XQ. Diameters A and B (reference ring and mesh-electrode ring) are concentric within 250μm

Output capacitance

Since the Plumbicon tube itself produces negligible noise, the signal-to-noise ratio obtained in a camera depends on the performance of the head amplifier. However, the performance which can be achieved is governed by the effective capacitance in parallel with the amplifier input, and a significant improvement can be obtained if the output capacitance of the tube is reduced. In the rear loading version of the 19XQ the conventional target electrode contact ring gives a reduction of the output capacitance by about 2pF. The location of the contact is fixed with reference to the preferred direction of the line scan; the spring contact in the yoke assembly has to be positioned accordingly.

Choice of yoke assembly

The type AT1115 yoke assembly is recommended for colour camera construction where the rear loading version of the 19XQ is to be used.

For use with front loading tubes (incorporating the conventional contact ring in place of the ceramic ring) in colour cameras the yoke assembly type AT1116 is recommended. For monochrome cameras the units AT1102 (with alignment magnets) or AT1103 (with alignment coils) are recommended.

Anti-comet-tail gun

The 19XQ incorporates an anti-comet-tail (ACT) gun which eliminates the undesirable effects of blooming, comet-tail and washed-out areas of picture which can occur when televising scenes containing excessively bright areas. When ACT is operating, the effective light transfer characteristic is as shown in Fig. 2. Up to the knee the linear (unity gamma) characteristic is retained, while after the knee has been reached the characteristic still exhibits a grey scale although it is greatly compressed. The knee level is adjusted by varying the magnitude of the cathode pulse.

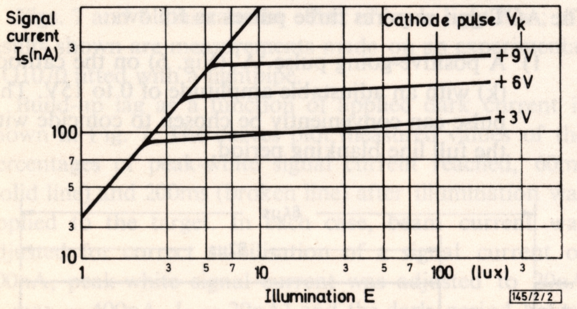
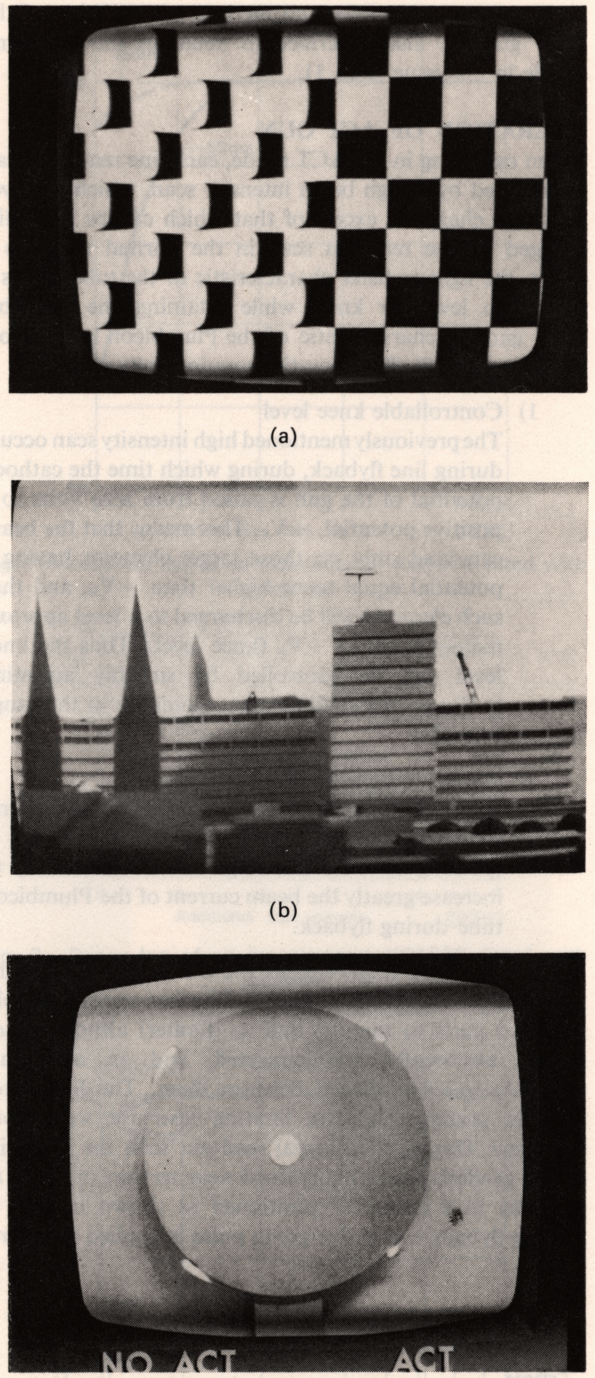


Fig. 2—Light transfer characteristic of Plumbicon tube fitted with ACT gun

Highlights up to and over 5 lens stops in excess of normal picture white are handled without blooming, comet-tail and distortion appearing in the picture. This is shown in Figs. 3(a), (b) and (c), which were photographed directly from a picture monitor. They show a split-screen display, with ACT in operation only on the right half of the display Fig. 3(a) shows a chequer-board pattern and the effect on blooming when the ACT pulses are applied to the gun electrodes during only the second half of each line scanning period. Fig. 3(b) shows a low-contrast scene against a bright sky; the grey scale in the foreground is not changed by the ACT pulses. In Fig. 3(c) the effect of the comet-tail is shown by moving bright lamps against a dark background. The brightness of the lamps corresponds to about 250 lux on the target. In all cases the beam current was set to stabilise a signal current of 400nA, and the ACT knee set to 300nA, corresponding to about 7·5 lux on the tube.



(a)

(b)

(c)

Fig. 3—Split-screen display showing improvements achieved by ACT gun
(a) Chequer-board pattern
(b) Low-contrast scene against bright sky
(c) Moving bright lamps against dark background

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*Registered trade mark for television camera tubes

The design principles and method of operation of the ACT gun are also described in detail in the preceding article in this issue (Ref. 1).

OPERATION OF ACT GUN

When operating in the ACT mode, each line read-out scan is preceded by a high beam intensity scan, which removes all target charge in excess of that which can be fully discharged by the read-out scan in the normal way. As a result, the light transfer characteristic of the tube shows a saturation level, or knee, while retaining the desirable unity gamma characteristic of the Plumbicon layer below this knee (Ref. 2). The operating requirements are:

1) Controllable knee level
   The previously mentioned high intensity scan occurs during line flyback, during which time the cathode potential of the gun is raised from zero volts to a positive potential, $+V_k$. This means that the beam can land only on those target elements having a potential equal to or higher than $+V_k$, and that such elements will be discharged to a level approximately equal to $+V_k$ (knee level). Thus the knee level can be controlled by suitably adjusting $+V_k$; a typical adjustment would be in the range 5 to 15V.

2) Ability to handle very bright areas
   Areas of the target exposed to very intense illumination may reach a potential of $+V_T$, which is typically 45V. To discharge this it is necessary to increase greatly the beam current of the Plumbicon tube during flyback.

To meet these requirements the triode gun used in the XQ1070 was modified as follows. The first anode was split into two parts a_1 (anode) and a_2 (limiter) although they remain electrically interconnected, and an additional electrode (g_2) was placed between them. The limiter-to-cathode spacing and the limiting aperture were both increased. During the normal read-out scan the potential of the g_2 electrode is maintained near to that of $a_1 + a_2$ resulting in a crossover positioned as shown in Fig. 4. During flyback a negative-going pulse is applied to g_2 and simultaneously a positive-going pulse is applied to g_1. These pulses cause an increase in cathode current, together with the formation of a second crossover in or near the plane of the a_2 aperture, and result in a greatly increased, divergent beam entering a_3, as shown in Fig. 5. The beam current may be as great as 100μA.

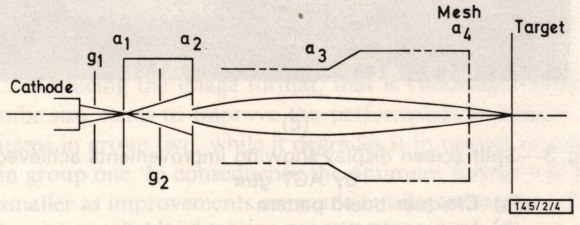

Fig. 4—ACT gun configuration showing normal read-out beam

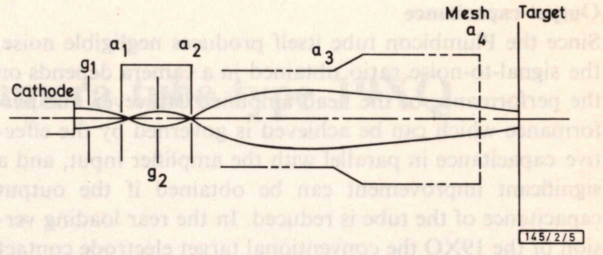

Fig. 5—ACT gun showing the high intensity defocused beam introduced during flyback

CALCULATION OF BEAM CURRENT REQUIREMENTS DURING ACT OPERATION

The effective target capacitance of the 1-inch Plumbicon tube is such that a typical operational peak-white signal current of 200nA corresponds to a potential excursion of about 6V. The beam current needed for correct stabilisation will be about 500nA, taking into account the transmission of the mesh electrode and the beam acceptance of the target surface. If the knee is placed so that all signals above normal picture white are limited, then $V_k = 6V$. For a target voltage V_T of 45V, the maximum potential excursion to be erased during flyback will be (45−6)V or about 40V. If erasure occurred during line scan a current of 40/6 × 500nA or 3·3μA would be needed, but this must be multiplied by the ratio

$$\frac{\text{Read-out scan time}}{\text{ACT scan time}} = \frac{50}{5} = 10$$

and then multiplied by a further factor of 2 or 3 to account for beam defocusing so that in total, a current of 75 to 100μA is required.

CIRCUIT REQUIREMENTS FOR ACT OPERATION

The ACT gun requires three pulses as follows:

1) A positive-going pulse 'A' (Fig. 6) on the cathode (k) with an adjustable amplitude of 0 to 15V. This pulse can conveniently be chosen to coincide with the full line blanking period.

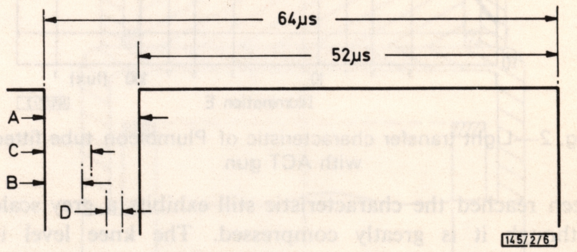

Fig. 6—Pulse timing of the ACT gun for the CCIR system
A—line blanking period ≃ 12μs, V_k pulsed
B—line flyback ≃ 5μs
C—ACT period ≃ 6μs, g_1 and g_2 pulsed
D—clamp ≃ 2 to 3μs

2) A positive-going pulse 'C' (Fig. 6) on the control grid (g_1) with a fixed amplitude of 20 to 30V, with respect to the d.c. level of the control grid voltage during the read-out mode. The length of this pulse should be chosen so that it just exceeds the line flyback time.

3) A negative-going pulse on electrode g_2 with a fixed amplitude of 210 to 250V with respect to the d.c. level of g_2 voltage during the read-out mode. The length and timing of this pulse should coincide with the pulse on g_1.

The impedances of the pulse supplies should be sufficiently low to prevent distortion. The peak currents flowing in the various electrodes during ACT operation will be roughly as indicated:

Cathode	k	1mA
Control grid	g_1	0
Anode 1 + 2	$a_1 + a_2$	1mA
Auxiliary grid	g_2	150μA
Wall anode	a_3	300μA
Mesh	a_4	300μA

In the presence of highlights, peak signal currents of up to 50μA may be fed to the head amplifier during flyback. Special measures may have to be taken to prevent temporary overloading.

BEAM DISCHARGE LAG

One of the significant features of the Plumbicon tube target is its freedom from photoconductive lag. In consequence the predominant lag mechanism is beam discharge lag, and in practice it is this lag, rather than signal-to-noise ratio, which sets the lower limit of scene brightness at which acceptable colour pictures can be televised.

Two measures have been incorporated in the 19XQ to improve its performance in respect of beam discharge lag. These are, firstly, the incorporation of an electron gun having an improved electron velocity spread in the read-out beam, and secondly, provision of a means for easily introducing controlled bias lighting via a lightpipe.

Figs. 7 and 8 illustrate the effect of such light bias; the results shown are measurements made on an experimental XQ1070 fitted with a lightpipe.

Build-up lag as a function of applied dark current is shown in Fig. 7. The curves plot measured values of the percentages of peak-white signal current reached, 60ms (solid line) and 200ms (broken line) after illumination was applied to the target. In each case, beam current was adjusted for correct stabilisation of a signal current of 400nA, peak-white signal current was adjusted to 20nA (I_t max = 400nA, I_S = 20nA) and the dark period before illumination was applied was 10 seconds. Decay lag as a function of applied dark current is shown in Fig. 8. The curves plot measured values of the residual signal as percentages of a peak-white signal current, 60ms (solid line) and 200ms (broken line) after illumination has been removed. The same operating conditions apply as for build-up lag.

Both figures show that, even with an additional bias-light-induced dark current as low as 2nA a remarkable improvement, especially in build-up lag, is obtained.

The combination of improved gun and light bias results in an even greater improvement in performance in the 19XQ Plumbicon tube. This is seen in Figs. 9 and 10, obtained under identical conditions to Figs. 7 and 8.

The improvement in basic lag performance, together with the improvement achieved by the introduction of bias lighting, makes the 19XQ very suitable for use in one-tube sequential colour cameras. The three oscillograms shown in Fig. 11 illustrate this.

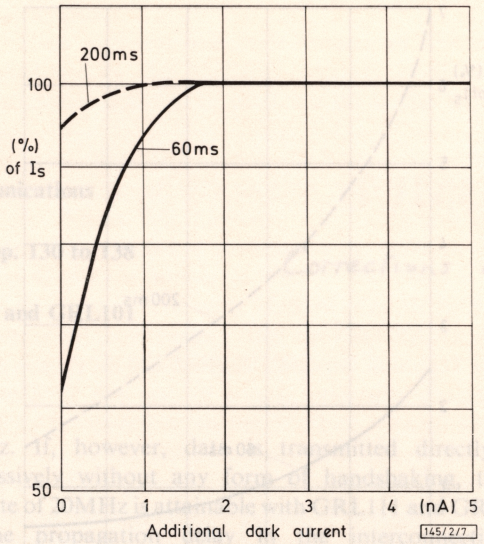

Fig. 7—Build-up lag of an experimental XQ1070 fitted with lightpipe

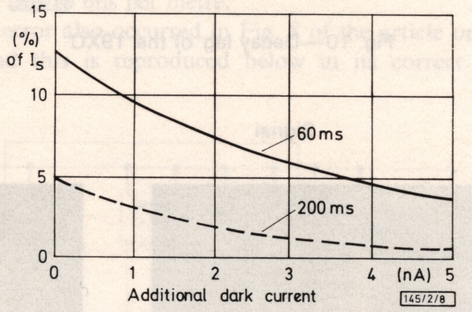

Fig. 8—Decay lag of an experimental XQ1070 fitted with lightpipe

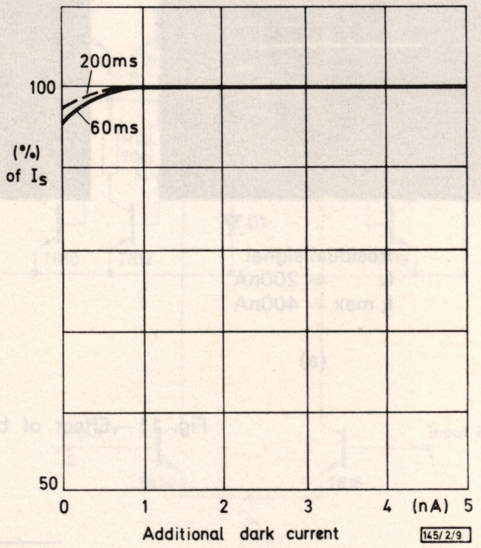

Fig. 9—Build-up lag of the 19XQ

An experimental camera fitted with a 19XQ Plumbicon tube was focused on a test pattern consisting of a white

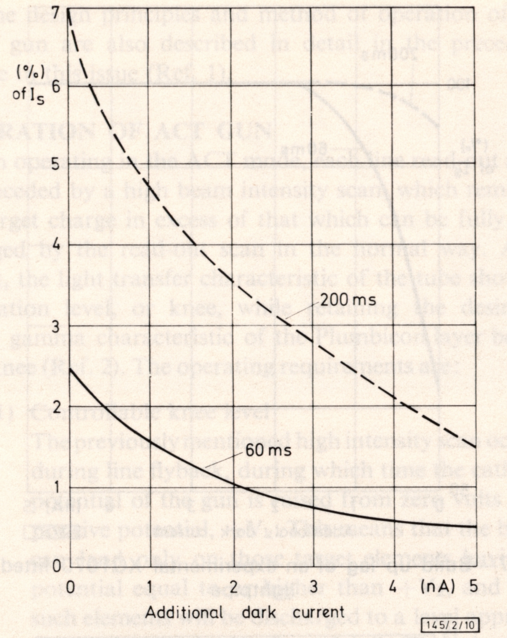

Fig. 10—Decay lag of the 19XQ

vertical bar whose brightness could be varied on a dark background. This vertical bar was illuminated only during every third field (20ms). The beam current of the 19XQ was set to stabilise 400nA. With the signal current from the white bar set to 200nA peak, the residual signal in the second field is already too small to be measured (Fig. 11a). Next the brightness of the white bar is reduced to give a peak signal current of 50nA. The residual signal, about 5%, is now clearly measurable (Fig. 11b). However, if an additional bias-light-induced dark current of 5nA is introduced, the residual signal once again is reduced to an immeasurably low level (Fig. 11c).

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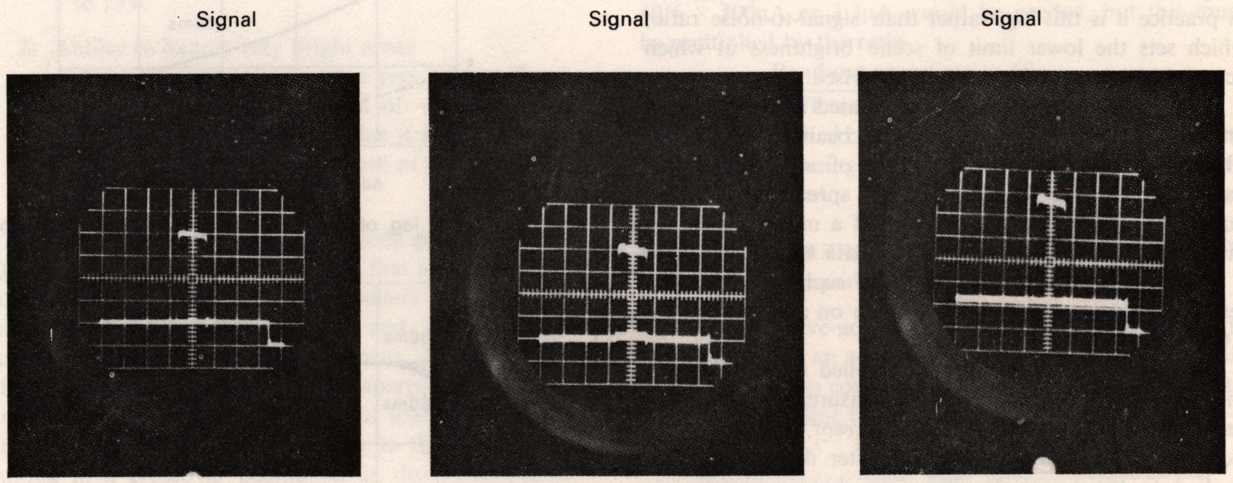
2. VAN ROOSMALEN, 'Advances in Electronics and Electron Physics', Vol. 28A, 1969, pp. 281 to 288.


Signal
Signal
Signal

Residual signal
I_s = 200nA
I_t max = 400nA
(a)

Residual signal
I_s = 50nA
I_t max = 400nA
(b)

Residual signal
I_s = 50nA
I_t max = 400nA
light bias applied
(c)

Fig. 11—Effect of bias lighting on decay lag in the 19XQ

Mullard Technical Communications

Vol. 11, No. 106, July 1970, pp. 130 to 138

Corrections carried out.

TTL interfacing with GRL111 and GRL101

The abstract in this article was misleading in implying that the maximum rate of operation was 2MHz. This rate, however, applies only to a system using 'full handshaking' with 6m of cable and some logic. Full handshaking is a system of character transfer often used in computer systems, in which four traverses of the cable are required to complete the transfer of the data: since a certain amount of additional logic has to be performed during this procedure, the net rate of data transfer is slowed down to 2MHz. If, however, data is transmitted directly and successively without any form of handshaking, then a bit-rate of 20MHz is attainable with GRL111 and GRL101.

The propagation delay in the interconnection is typically 39ns (that is, 14ns for the transmitter and 25ns for the receiver) plus the propagation delay of the cable, usually 5ns to 6ns per metre.

An error also occurred in Fig. 8 of the article on page 135 and this is reproduced below in its correct form.

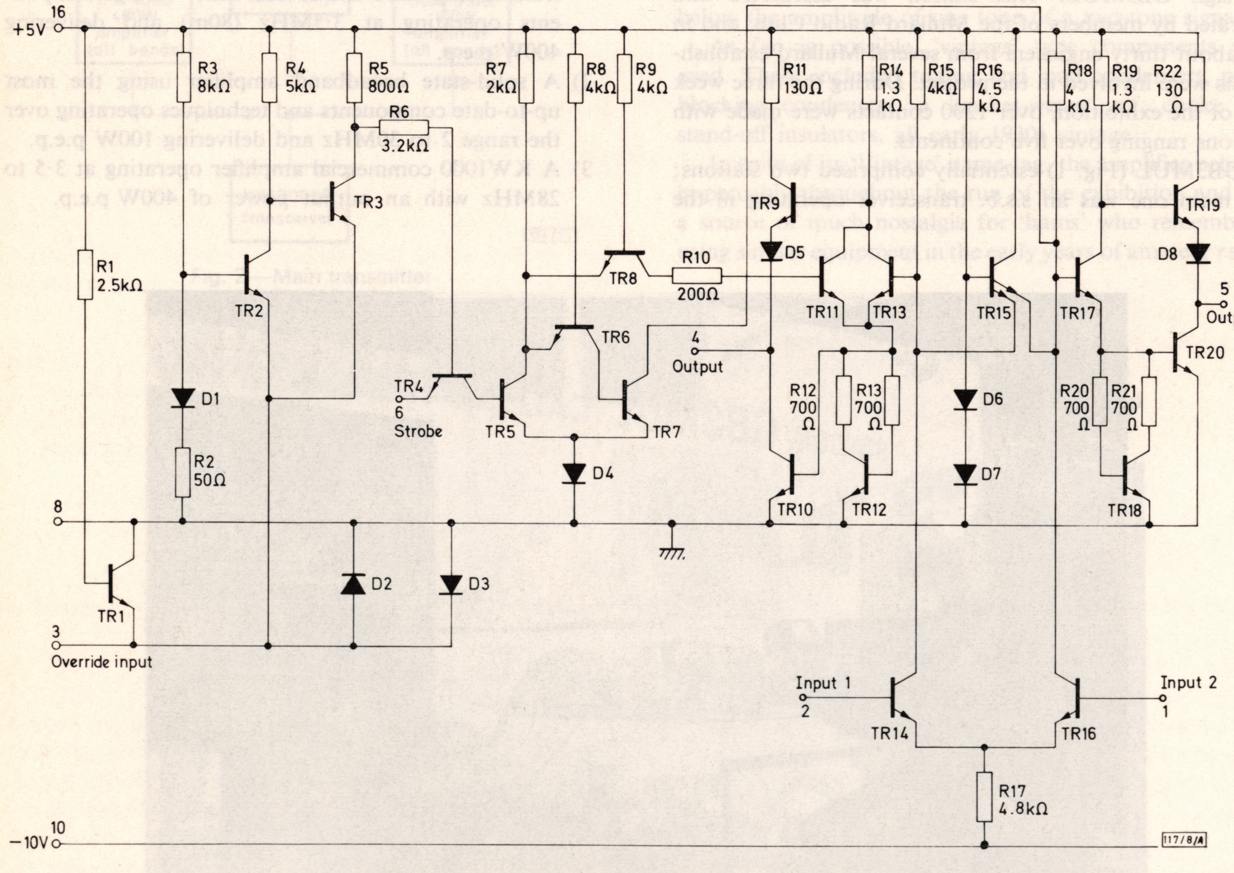

16
+5V
R1 2.5kΩ
R3 8kΩ
R4 5kΩ
R5 800Ω
R6 3.2kΩ
R7 2kΩ
R8 4kΩ
R9 4kΩ
R10 200Ω
R11 130Ω
R12 700 Ω
R13 700 Ω
R14 1.3 kΩ
R15 4kΩ
R16 4.5 kΩ
R17 4.8kΩ
R18 4 kΩ
R19 1.3 kΩ
R20 700 Ω
R21 700 Ω
R22 130 Ω
TR1
TR2
TR3
TR4
TR5
TR6
TR7
TR8
TR9
TR10
TR11
TR12
TR13
TR14
TR15
TR16
TR17
TR18
TR19
TR20
D1
D2
D3
D4
D5
D6
D7
D8
R2 50Ω
4 Output
5 Output
6 Strobe
8
3 Override input
Input 1 2
Input 2 1
10
−10V
117/8/A

Fig. 8.—Receiver GRL101

GB3MUL

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UDC 621.396.721

To celebrate the 50th anniversary of the founding of the Mullard Company, a Jubilee exhibition was held in the Electronics Centre at Mullard House from the 5th to the 24th of October, 1970. The exhibition, visited by over 28 000 people, paralleled the history and development of electronics over the past 50 years with the growth of the Company. Among the many exhibits, one which attracted a great deal of interest from visitors, technical and non-technical alike, was the amateur transmitting station, call-sign GB3MUL. This station was assembled and operated by members of the Mullard Radio Club, and in all, about thirty engineers from several Mullard establishments were involved in the project. During the three week run of the exhibition, over 1200 contacts were made with stations ranging over five continents.

GB3MUL (Fig. 1) essentially comprised two stations; the main one was an s.s.b. transceiver operating in the 3·5, 7, 14, 21 and 28MHz (80, 40, 20, 15 and 10m) amateur bands, the other a transmitter-and-receiver operating at 144MHz v.h.f.

MAIN TRANSMITTER

The layout of the main transmitter is shown in Fig. 2. As shown, a KW 2000B s.s.b. transceiver operates as an exciter into a choice of three linear power amplifiers:

1) A 'vintage' amplifier incorporating a 45-year-old transmitting valve and several other vintage components operating at 3·5MHz (80m) and delivering 400W p.e.p.
2) A solid-state broadband amplifier using the most up-to-date components and techniques operating over the range 2 to 30MHz and delivering 100W p.e.p.
3) A KW1000 commercial amplifier operating at 3·5 to 28MHz with an output power of 400W p.e.p.

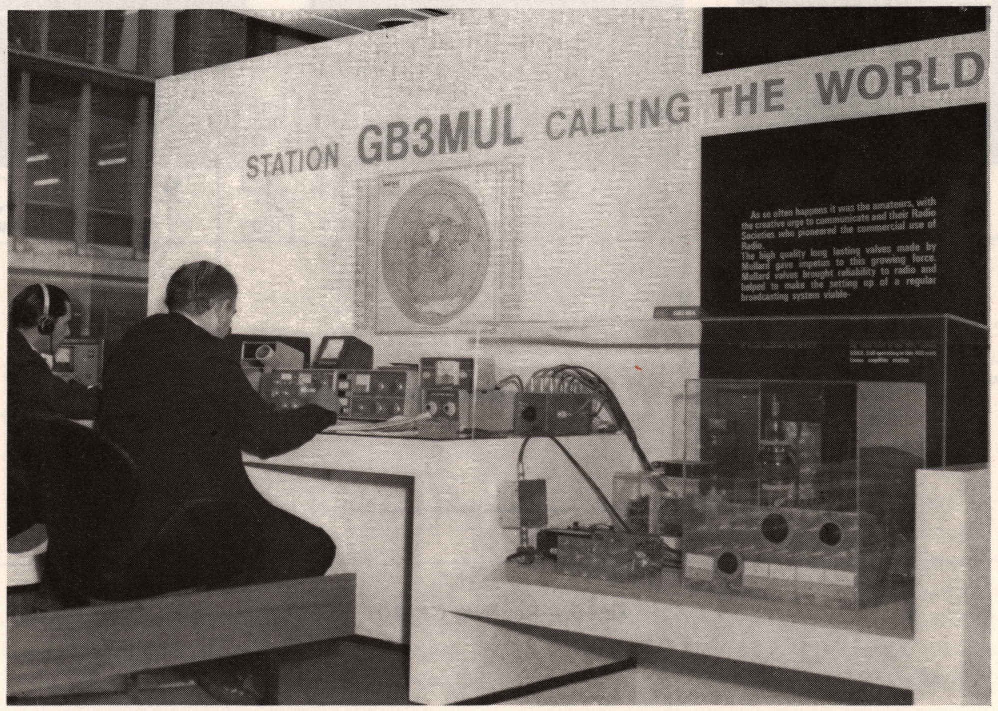

STATION GB3MUL CALLING THE WORLD

Fig. 1—Station GB3MUL

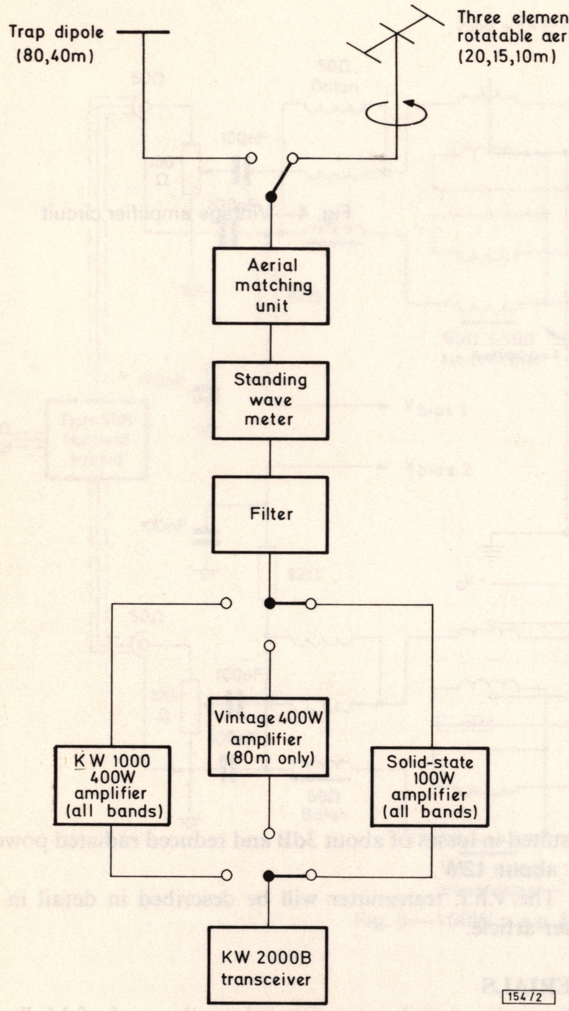


Fig. 2—Main transmitter

Vintage amplifier

The vintage amplifier was built around an SW2 triode, manufactured by the Mullard company in about 1925 and originally sold for £9 (£10 10s 0d in the Irish Free State).

The particular SW2 used in the Vintage amplifier was owned originally, in 1923 to 1925, by Mr. Cookson of Blackpool, Lancs. Mr. Cookson was a keen amateur and operated for a number of years under the call-sign G6KK. Station G6KK is shown in Fig. 3. The SW2 is in the centre foreground. The early Mullard calendar (left), from the 'Beautiful Girls Series', fixes the date of the photograph exactly as 22nd April, 1925.

The SW2 was not, of course, originally designed for linear s.s.b. operation. In the Mullard Vintage amplifier (right, Fig. 1), the valve operates in a neutralised tuned-anode tuned-grid circuit in class AB2. The circuit is shown in Fig. 4. The h.t. supply for the SW2 is 3·5kV and the idling current is 25 to 30mA. An 11V, 10A supply feeds the tungsten bright-emitter filament. Grid-drive is −150 to +50V giving a peak anode current of 400mA. A 50W, 2kΩ resistor provides the grid damping necessary for s.s.b. operation. This presents a more constant load to the driver stage and reduces the distortion of the input signal. It is this resistor which absorbs a large proportion of the drive power. Intermodulation products are more than 30dB below the amplitude of one tone of a two-tone signal.

As far as possible, 'vintage' type components were used. These included tuning and load condensers, paper blocking condensers, a 'basket-weave' r.f. choke and stand-off insulators, all early 1930s vintage.

In spite of its 'Vintage' name-tag, the amplifier behaved impeccably throughout the run of the exhibition and was a source of much nostalgia for 'hams' who remembered using similar equipment in the early years of amateur radio.

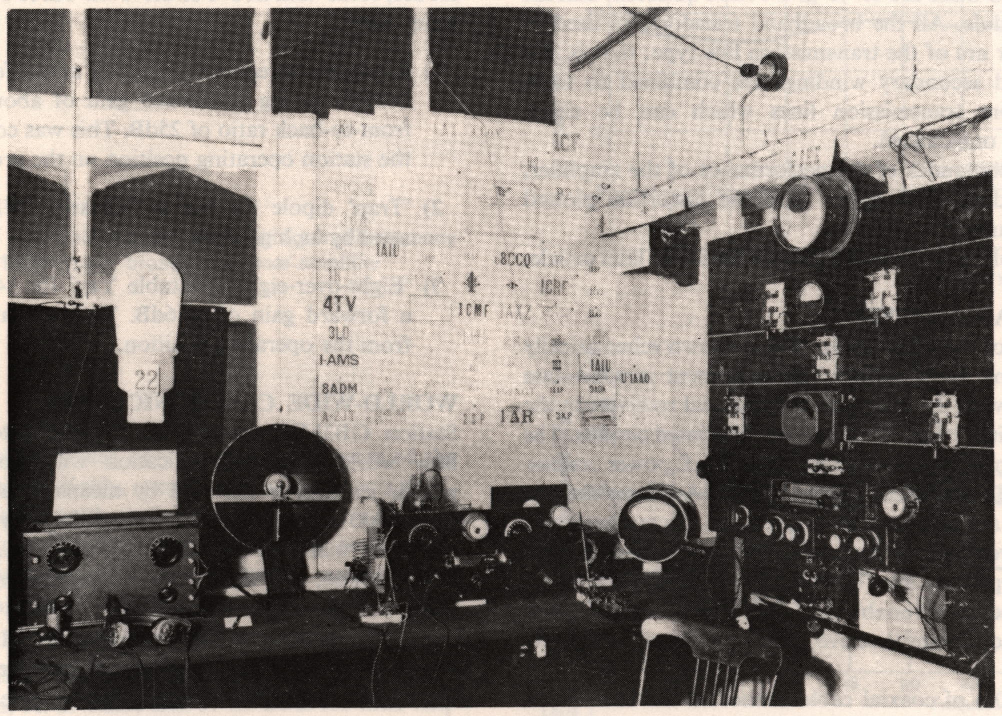


Fig. 3—Station G6KK, 1925

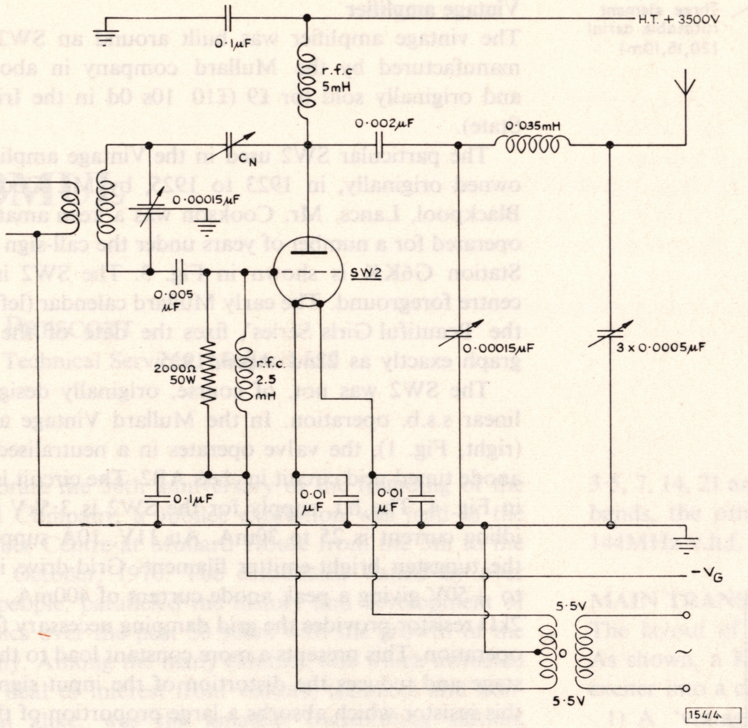

0·1μF
H.T. + 3500V
r.f.c
5mH
0·002μF
0·035mH
C_N
DRIVE
0·00015μF
SW2
0·005
μF
2000Ω
50W
r.f.c
2.5
mH
0·00015μF
3 x 0·0005μF
0·1μF
0·01
μF
0·01
μF
−V_G
5·5V
0
~
5·5V
154/4

Fig. 4—Vintage amplifier circuit

100W p.e.p. broadband linear amplifier
The 100W p.e.p. solid-state broadband linear amplifier uses four 810BLY transistors in a special power combining network. Each push-pull pair forms the basis of a module delivering 50W p.e.p. over the range 2 to 30MHz untuned. The amplifier circuit is shown in Fig. 5.

Separate bias supplies are used for the two 50W modules, and these are set to give 50mA quiescent current in each module. All the broadband transformers used in the amplifier are of the transmission line type; that is, the primary and secondary windings are combined to form one or more transmission lines which can be either balanced or unbalanced.

To give some idea of the performance of the amplifier, Figs. 6a and 6b show power gain and distortion plotted against frequency.

This amplifier will be described in detail in a later article.

V.H.F. TRANSMITTER
The layout of the v.h.f. equipment is shown schematically in Figs. 7 and 8 (page 206). The equipment is solid-state throughout with the exception of the Racal receiver. In the 25W transmitter, the r.f. circuits are all printed circuits. The r.f. power amplifier uses two BLY93A v.h.f. power transistors in parallel driven by another BLY93A. Three channel frequencies are available from separate driver circuits.

In the receiver, a low-noise FET crystal-controlled converter operates into a Racal RA17 communications receiver used as a tunable i.f. amplifier between 19 and 21MHz. The transmit/receive switching circuit is entirely solid-state.

About 50m of coaxial cable connected the transmitter to the beam aerial on the roof of Mullard House and this resulted in losses of about 3dB and reduced radiated power to about 12W.

The v.h.f. transmitter will be described in detail in a later article.

AERIALS
The station aerials were situated on the roof of Mullard House, some 43m above street level. Three separate arrays were used:

1) Rotatable three-element beam aerial for 14, 21 and 28MHz giving a forward gain of about 8dB and a front-to-back ratio of 25dB. This was controlled from the station operating position on the ground floor.

2) 'Trap' dipole for use at 3·5 and 7MHz, and as a standby at higher frequencies.

3) 'Eight-over-eight' rotatable Yagi for 144MHz giving a forward gain of 12·6dB. This was also controlled from the operating position.

WORLD-WIDE COMMUNICATION
Station GB3MUL successfully demonstrated to visitors how world-wide communication with both fixed and mobile stations is achieved by means of amateur radio. Over 1000 contacts were made on the short-wave bands, including many as far afield as the U.S.A., Australia, South Africa, and Antarctica. In particular, contact was made with the station in the Philips Evoluon in Eindhoven, and with station VK20R, operated by Mr. M. Brown, Manager of Mullard Australia. Signal strength reports were excellent, a fact no doubt attributable to the height of the aerial array, some 43m above the ground.

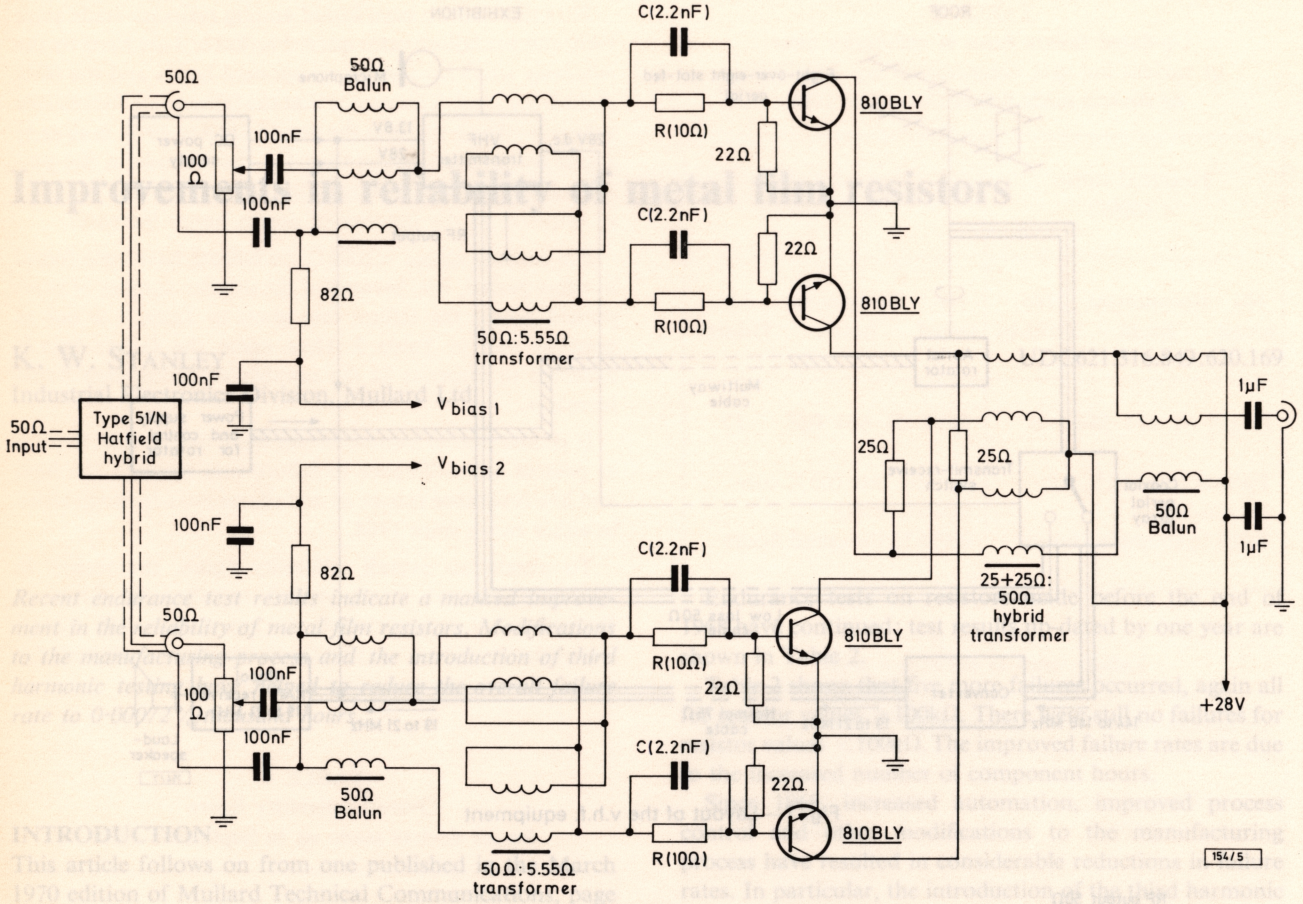
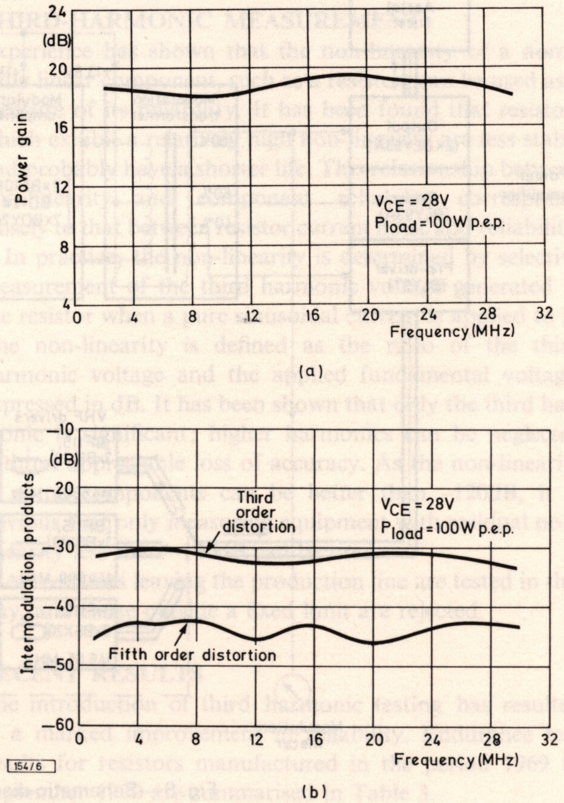

50Ω
50Ω
Balun
100nF
100
Ω
100nF
82Ω
50Ω:5.55Ω
transformer
C(2.2nF)
R(10Ω)
22Ω
810BLY
C(2.2nF)
22Ω
R(10Ω)
810BLY
100nF
V_bias 1
50Ω
Input
Type 51/N
Hatfield
hybrid
V_bias 2
100nF
82Ω
50Ω
100
Ω
100nF
100nF
50Ω
Balun
50Ω:5.55Ω
transformer
C(2.2nF)
R(10Ω)
22Ω
810BLY
C(2.2nF)
22Ω
R(10Ω)
810BLY
25Ω
25Ω
25+25Ω:
50Ω
hybrid
transformer
1μF
50Ω
Balun
1μF
+28V
154/5

Fig. 5—100W p.e.p. broadband linear amplifier circuit



(a)

(b)

Fig. 6—Power gain and distortion plotted against frequency for the 100W p.e.p. broadband linear amplifier

The v.h.f. station was only on the air for part of the time but operated reliably, averaging fifteen contacts daily. These were mainly with stations in Greater London and the Home Counties. However, occasional better-than-average propagation conditions allowed contact with stations in Yorkshire and Holland.

ACKNOWLEDGEMENTS: The author wishes to thank H. W. Haynes, A. J. Rees, and P. G. Giles for their help in the preparation of this article.

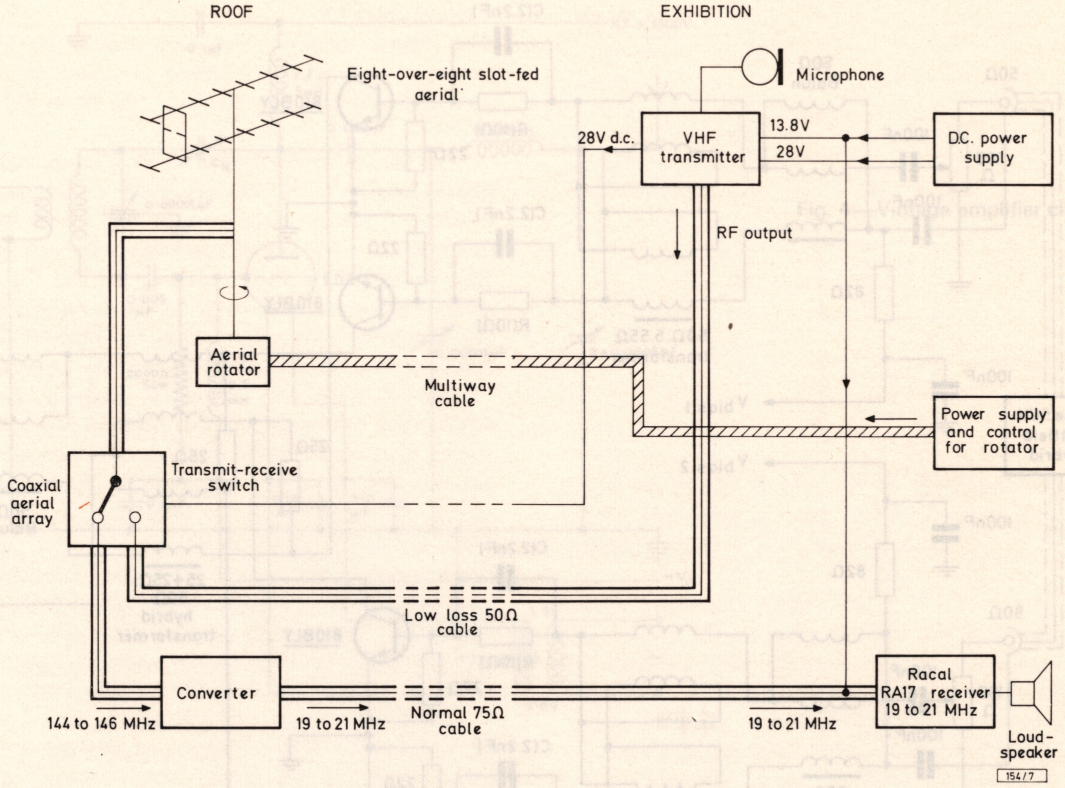

ROOF
EXHIBITION
Eight-over-eight slot-fed aerial
Microphone
28V d.c.
VHF transmitter
13.8V
28V
D.C. power supply
RF output
Aerial rotator
Multiway cable
Power supply and control for rotator
Coaxial aerial array
Transmit-receive switch
Low loss 50Ω cable
Converter
Racal RA17 receiver 19 to 21 MHz
Loud-speaker
144 to 146 MHz
19 to 21 MHz
Normal 75Ω cable
19 to 21 MHz
154/7

Fig. 7—Layout of the v.h.f. equipment

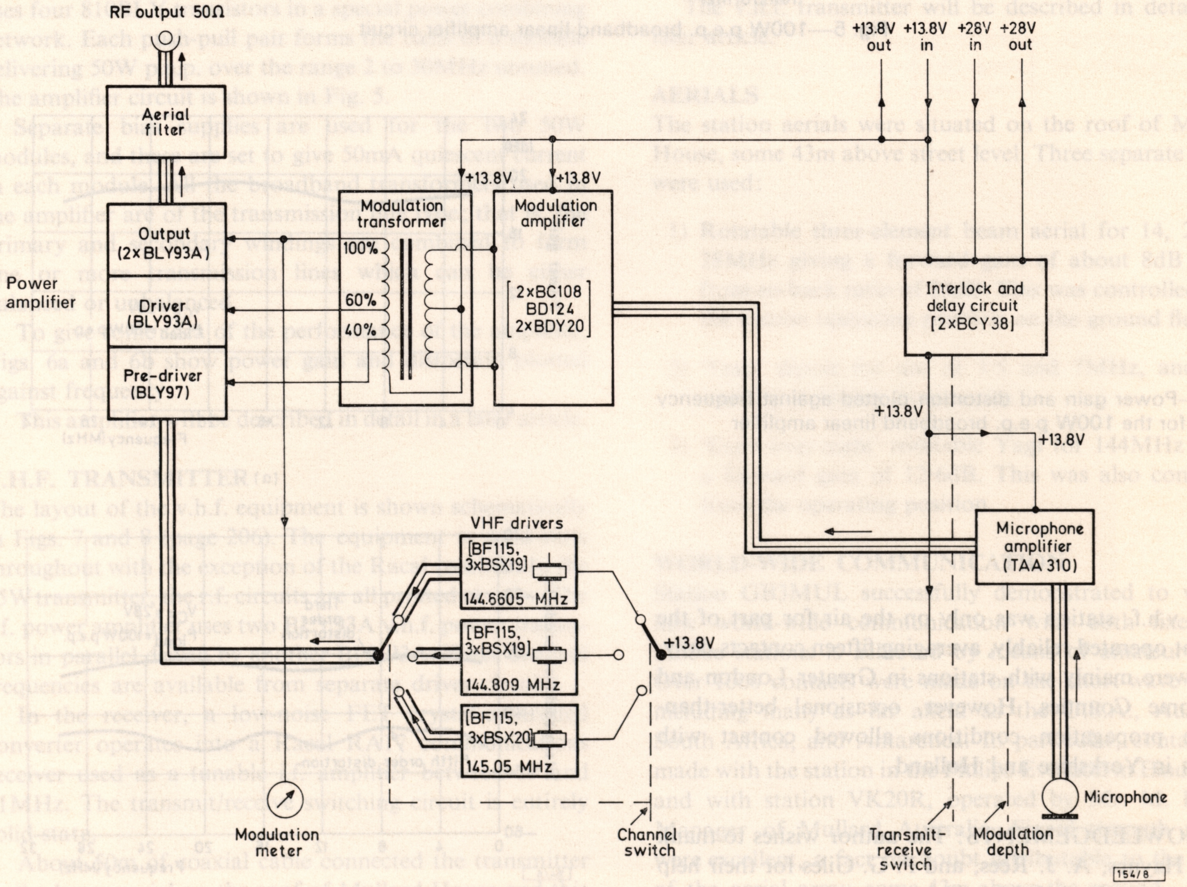

RF output 50Ω
Aerial filter
+13.8V
+13.8V
Output (2×BLY93A)
Driver (BLY93A)
Pre-driver (BLY97)
Power amplifier
Modulation transformer
100%
60%
40%
Modulation amplifier
[2×BC108 BD124 2×BDY20]
+13.8V out
+13.8V in
+28V in
+28V out
Interlock and delay circuit [2×BCY38]
+13.8V
+13.8V
Microphone amplifier (TAA 310)
VHF drivers
[BF115, 3×BSX19] 144.6605 MHz
[BF115, 3×BSX19] 144.809 MHz
[BF115, 3×BSX20] 145.05 MHz
+13.8V
Microphone
Modulation meter
Channel switch
Transmit-receive switch
Modulation depth
154/8

Fig. 8—Schematic diagram of the 25W, 2m transmitter

Improvements in reliability of metal film resistors

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UDC621.316.849:620.169

Recent endurance test results indicate a marked improvement in the reliability of metal film resistors. Modifications to the manufacturing process and the introduction of third harmonic testing have helped to reduce the overall failure rate to 0·00072%/thousand hours.

INTRODUCTION

This article follows on from one published in the March 1970 edition of Mullard Technical Communications, page 94. In that article the behaviour of Mullard metal film resistors, styles MR25 and MR30, in long-term endurance and climatic tests was described. The tests were carried out on random samples taken from normal production in the period 1964 to the end of 1968 and reliability figures were quoted in terms of failure rates.

The results of these tests, published in the earlier article, are repeated in Table 1. As shown twelve failures were recorded, all for resistor values ⩾100kΩ.

TABLE 1

Failure rates in endurance tests at various hot-spot temperatures (up to 175°C) on devices made before the end of 1968

Nominal value <100kΩ			Nominal value ⩾100kΩ		
No. tested	Component hours	No. failures	No. tested	Component hours	No. failures
9171	44 038 084	0	4743	27 907 368	12
Failure rate (60% confidence level) 0·002%/thousand hours			Failure rate (60% confidence level) 0·049%/thousand hours		

Endurance tests on resistors made before the end of 1968 have continued; test results up-dated by one year are shown in Table 2.

Table 2 shows that five more failures occurred, again all for resistor values ⩾100kΩ. There were still no failures for resistor values <100kΩ. The improved failure rates are due to the increased number of component hours.

Since 1968, increased automation, improved process control and other modifications to the manufacturing process have resulted in considerable reductions in failure rates. In particular, the introduction of the third harmonic measurement has proved highly successful in reducing the number of failures.

THIRD-HARMONIC MEASUREMENT

Experience has shown that the non-linearity of a nominally linear component, such as a resistor, can be used as a measure of its reliability. It has been found that resistors which exhibit a relatively high non-linearity are less stable and probably have a shorter life. This relationship between non-linearity and component reliability corresponds closely to that between resistor current noise and reliability.

In practice, the non-linearity is determined by selective measurement of the third harmonic voltage generated in the resistor when a pure sinusoidal current is applied to it. The non-linearity is defined as the ratio of the third harmonic voltage and the applied fundamental voltage, expressed in dB. It has been shown that only the third harmonic is significant; higher harmonics can be neglected without appreciable loss of accuracy. As the non-linearity of some components can be better than −120dB, it is obvious that only measuring equipment with residual non-linearity less than −140dB can be used.

All resistors leaving the production line are tested in this way, and those outside a fixed limit are rejected.

RECENT RESULTS

The introduction of third harmonic testing has resulted in a marked improvement in reliability. Endurance test results for resistors manufactured in the period 1969 to September 1970 are summarised in Table 3.

TABLE 2
Up-dated failure rates in endurance tests at various hot-spot temperatures (up to 175°C) on devices made before the end of 1968

Nominal value <100kΩ			Nominal value ≥100kΩ		
No. tested	Component hours	No. failures	No. tested	Component hours	No. failures
12 232	81 414 564	0	6458	51 654 028	17
Failure rate (60% confidence level) 0·001%/thousand hours			Failure rate (60% confidence level) 0·036%/thousand hours		

TABLE 3
Failure rates in endurance tests at various hot-spot temperatures (up to 175°C) on devices made in the period 1969 to September 1970

Nominal value <100kΩ			Nominal value ≥100kΩ		
No. tested	Component hours	No. failures	No. tested	Component hours	No. failures
6597	24 914 264	0	3955	18 266 184	0
Failure rate (60% confidence level) 0·004%/thousand hours			Failure rate (60% confidence level) 0·005%/thousand hours		

No failures have been found among resistors made since 1968 and the failure rates quoted in Table 3 are fixed by the relatively small number of component hours and the 60% confidence level. This means that the failure rate for resistor values ≥100kΩ, made in the period 1969 to 1970, is already about seven times better than for those made in the preceding period. It is expected that this factor will continue to improve as the number of device hours increases.

For resistor values <100kΩ, no failures have been found in either period, but, because of the smaller number of component hours, the failure rate given in Table 3 is not as good as that in Table 2. Here again the failure rate is expected to improve as the number of component hours increases.

It should not be assumed from these figures that there is at present any difference in failure rate between the high and low resistance ranges as no failures have been recorded in either range since 1968.

To obtain an overall reliability figure, the results in Tables 1, 2 and 3 are added together in Table 4. Statistically it is permissible to ignore pre-1969 figures for resistor values ≥100kΩ, as resistors untested for non-linearity are no longer in production.

TABLE 4
Overall reliability figure for all devices made up to September 1970

Total tested	Component hours	No. of failures
22 784	124 595 012	0
Failure rate (60%) 0·00072%/thousand hours		

It can be concluded that the failure rates of metal film resistors have decreased considerably since the end of 1968.